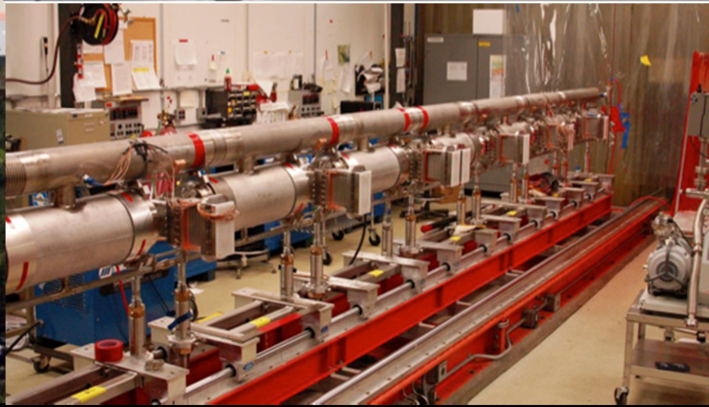
12 GeV CEBAF Transverse Emittance Evolution

Todd Satogata / Center for Advanced Studies of Accelerators



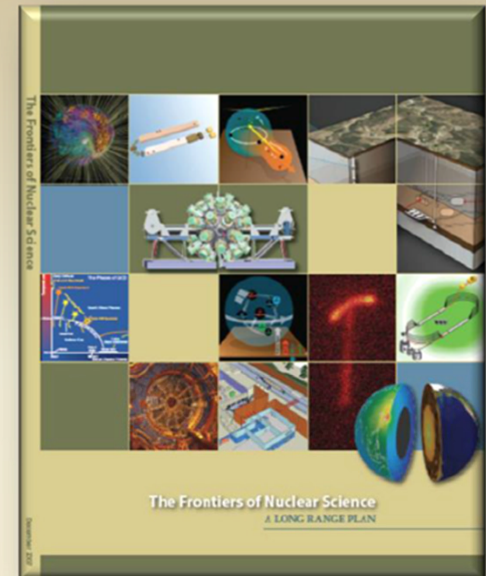
May 6 2015 WEBD1

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Outline

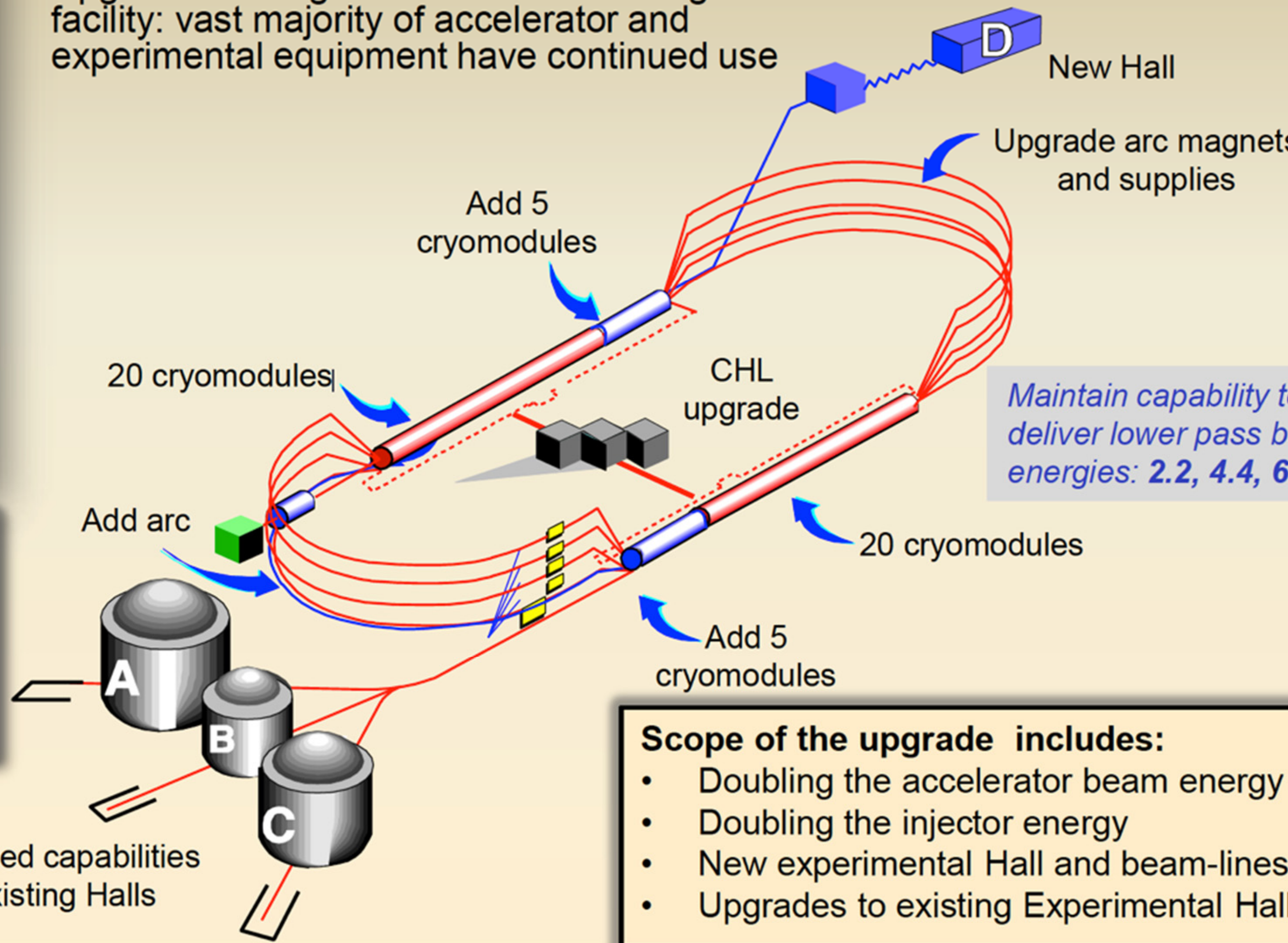
- **CEBAF Overview** and the **12 GeV Upgrade**
- **Optical Design** and **12 GeV Expectations**
- **Commissioning: Optics Matching** and **Operations Emittance Measurements**
- **CSR Suppression Experiment**
- **Conclusions**

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:

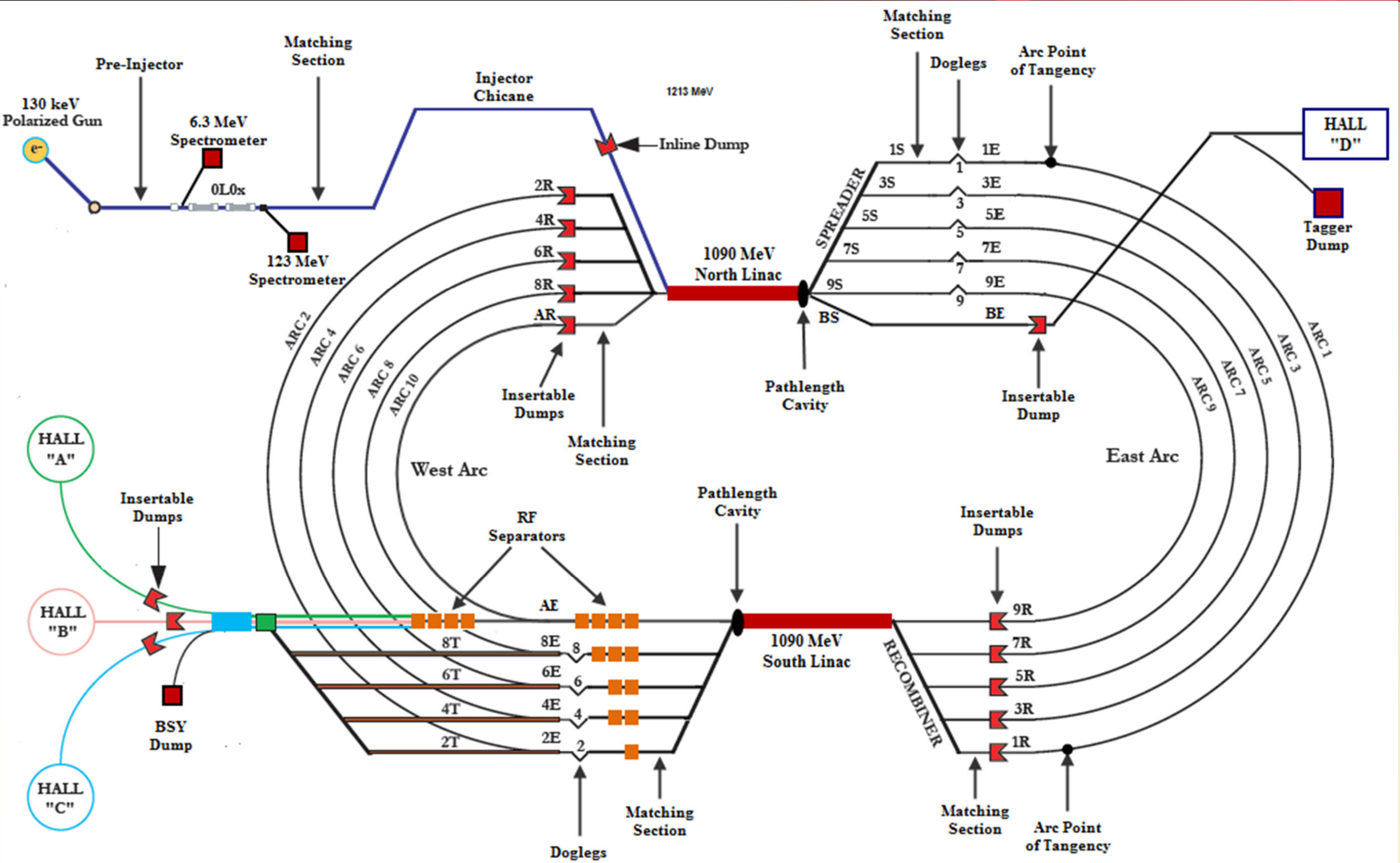
- Doubling the accelerator beam energy
- Doubling the injector energy
- New experimental Hall and beam-lines
- Upgrades to existing Experimental Halls

MOXGB2 (A. Freyberger, 12 GeV Commissioning/Ops)
THXB1 (R. Bachimanchi, 12 GeV SRF Performance)

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
Bunch charge	< 0.41 pC	< 0.36 pC
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%

CEBAF Detail Schematic



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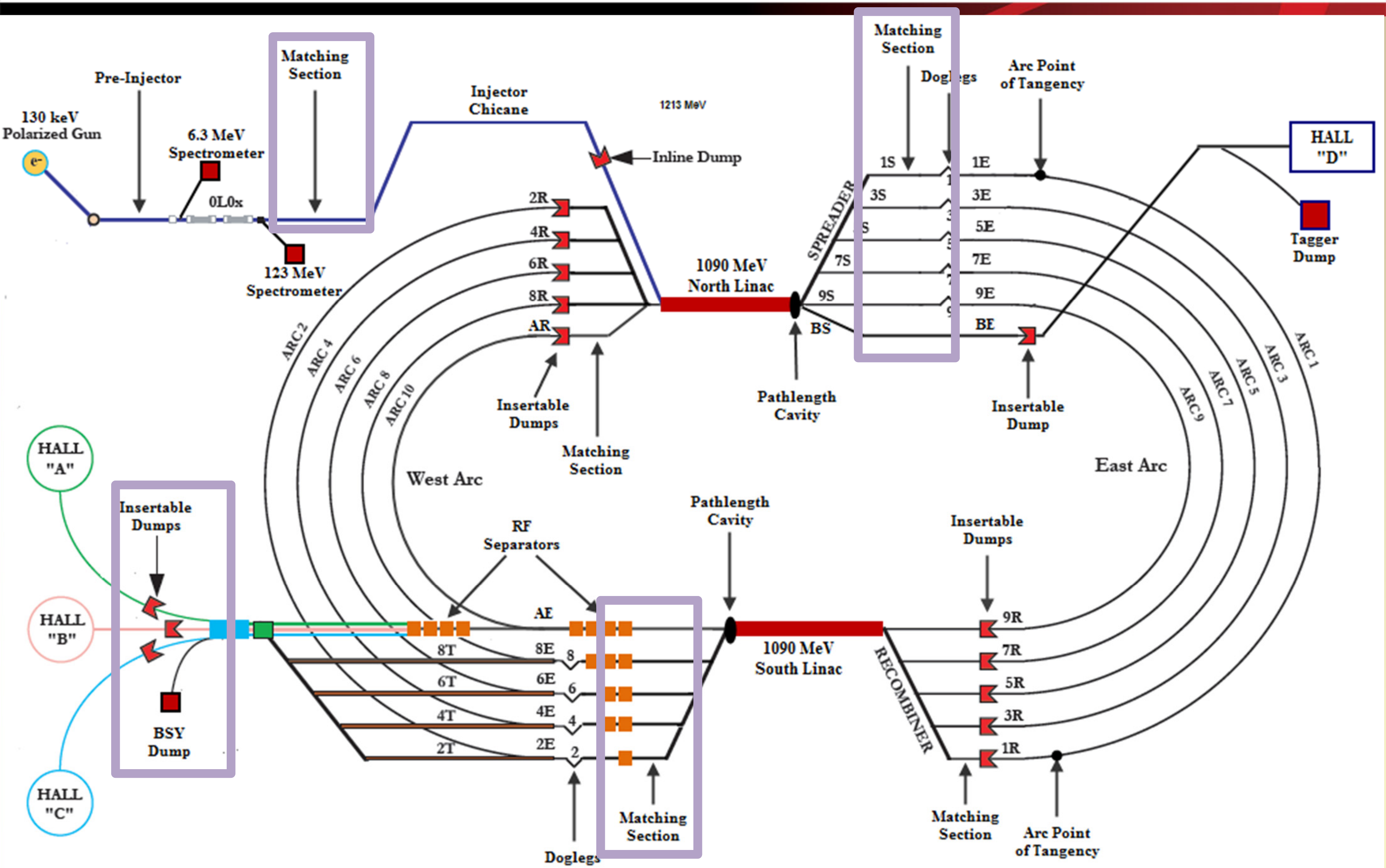
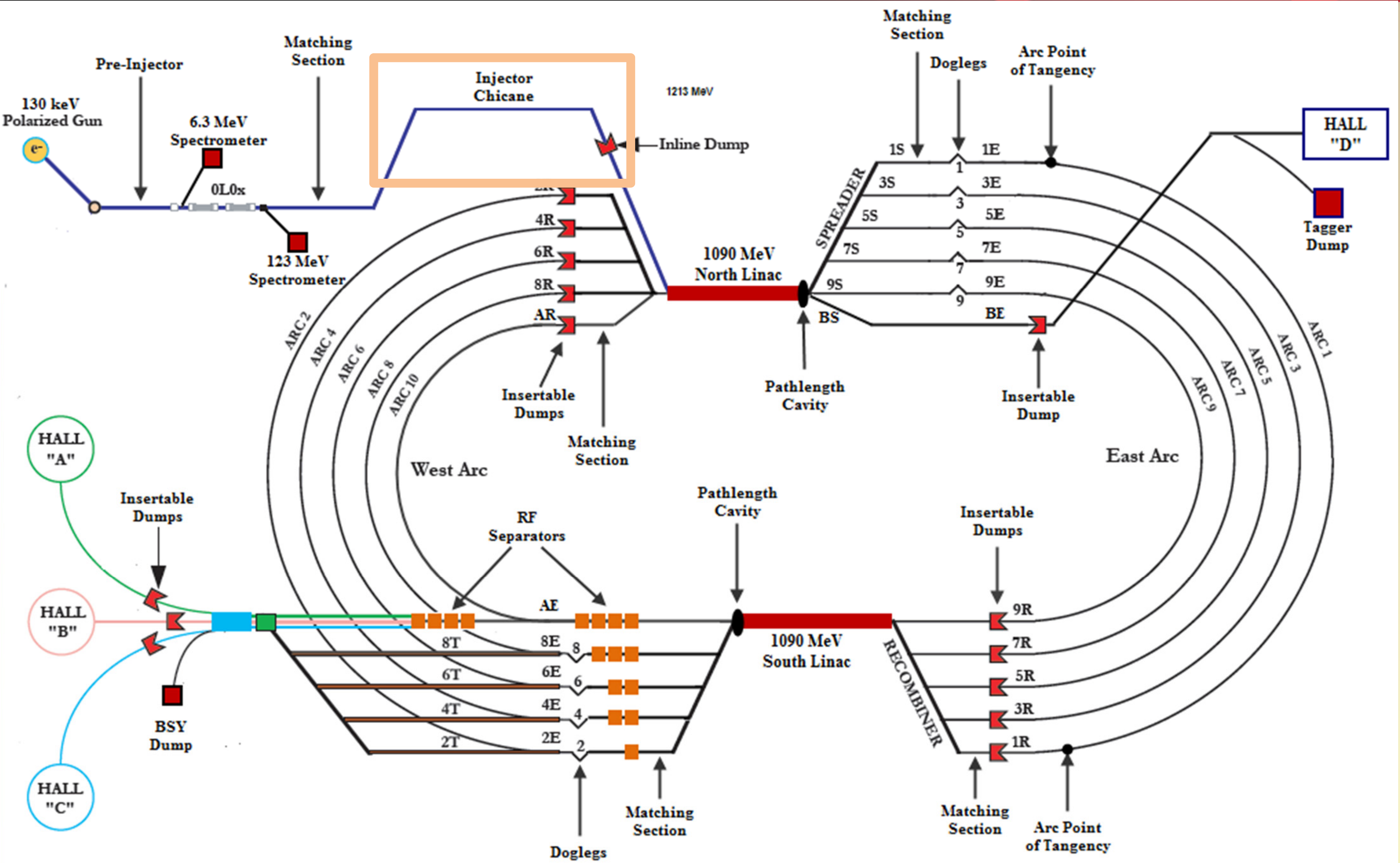
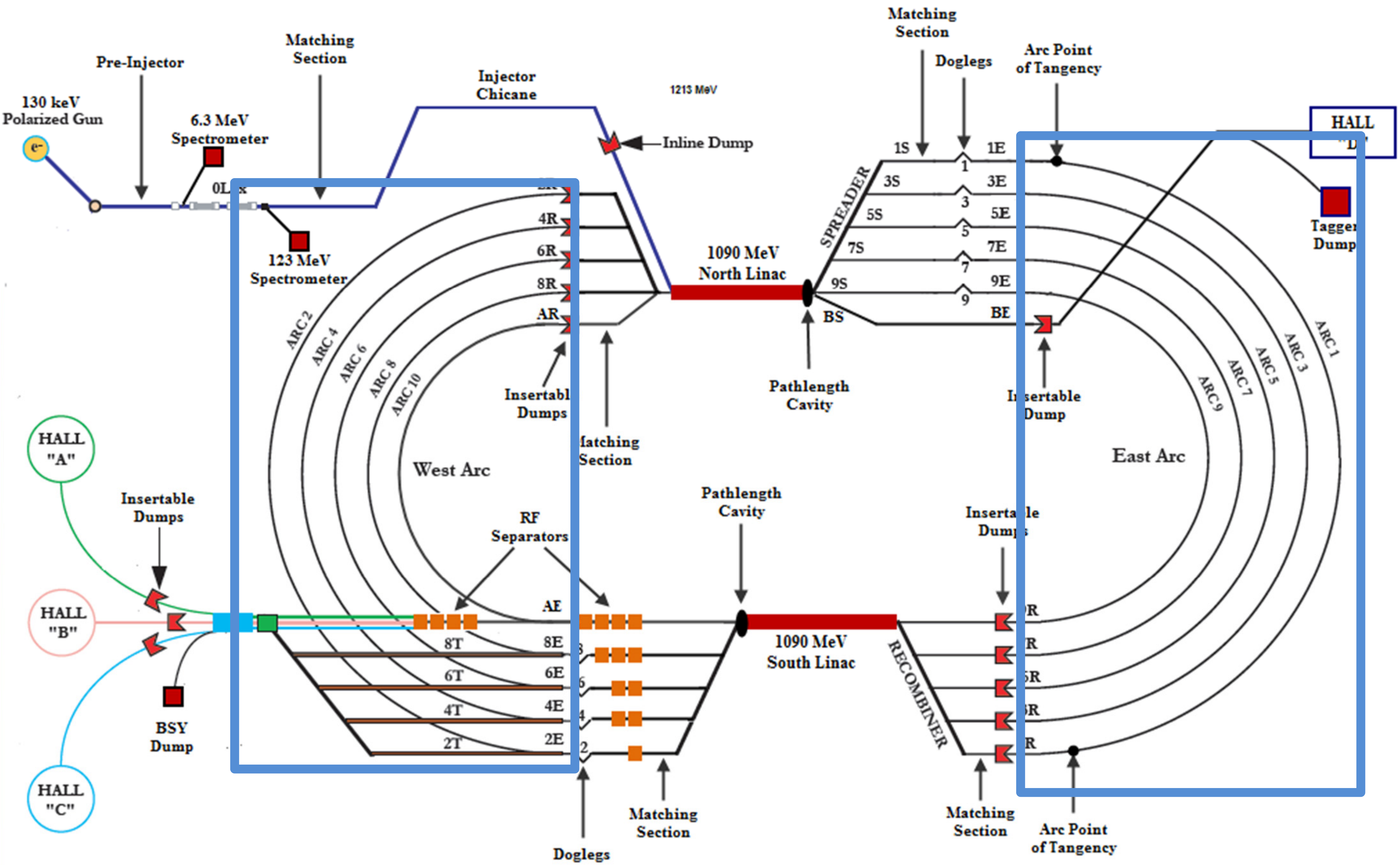
CEBAF Detail Schematic



CEBAF Detail Schematic



CEBAF Detail Schematic



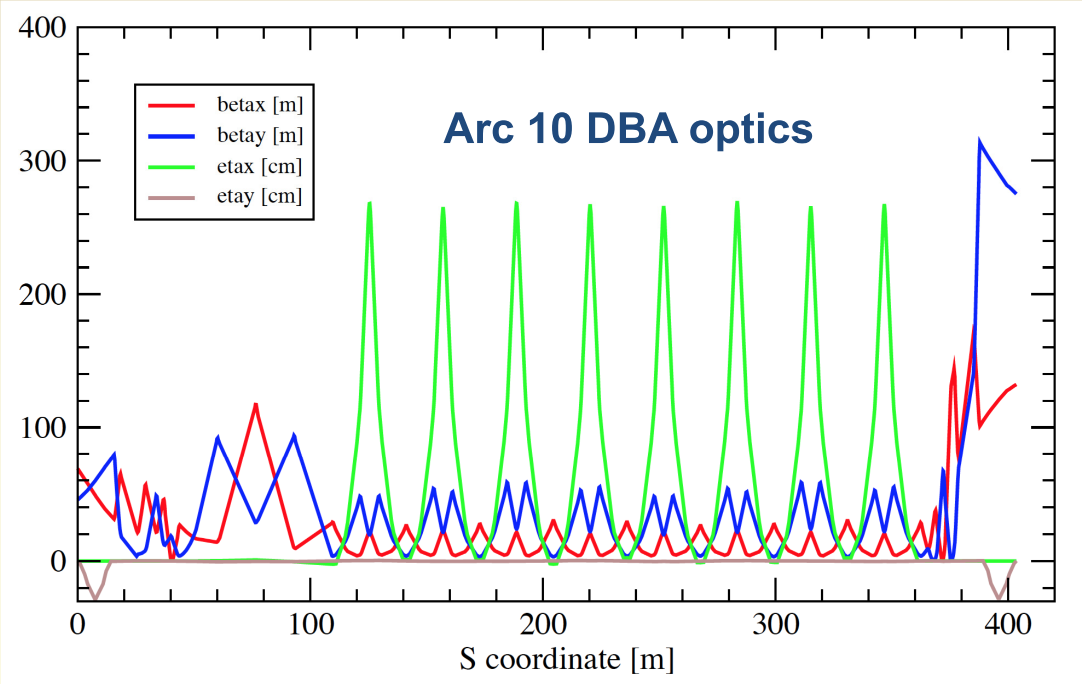
Synchrotron Radiation Emittance Growth

$$\Delta\epsilon \approx 2 \times 10^{-27} \left(\frac{\gamma^5}{\rho[\mathrm{m}]^{\;2}} \right) \langle \mathcal{H} \rangle$$

$$\sigma_{\mathrm{E}}^2 \approx 1.2 \times 10^{-33}\ \mathrm{GeV}^2 \left(\frac{\gamma^7}{\rho[m]^{\;2}} \right)$$

rms, geometric
180° multi-cell bend

Sands 1985, Douglas 1997



- Arc focusing very flexible: separate power supplies for all 32 arc quads
- Traditional CEBAF FODO cells ➔ DBA cells in higher arcs
- 30-40% reduction in $\langle \mathcal{H} \rangle$
  - Tradeoffs in M_{56}, matching

Transverse Emittance Evolution

Region	δp/p [$\times 10^{-3}$]	ϵ_x [nm]	ϵ_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

(Nearly) end to end elegant simulations with mitigation

Adiabatic damping dominated

Arcs 6-10 with optics reconfigured from FODO to DBA

Synchrotron radiation dominated

Emittances are geometric
All quantities are rms

from Y. Roblin

Emittance/Optics Campaign Strategy

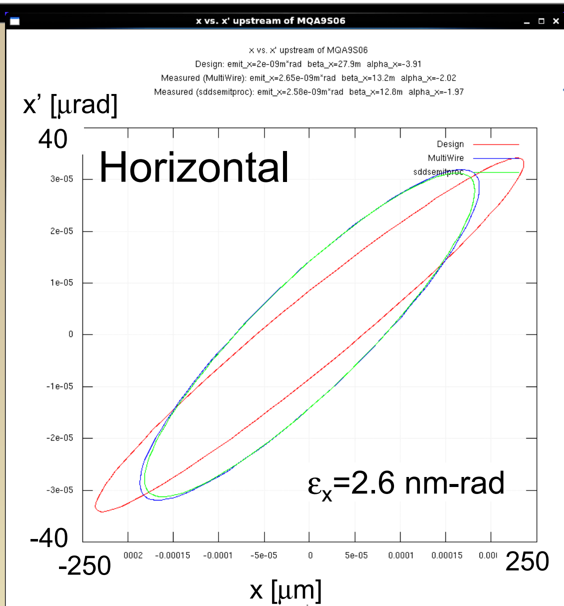
- Incorporate into **12 GeV optics commissioning**
  - Measure in all (available) matching regions
  - Single quad ➔ single wire scanner measurements
  - Improve automation, model integration in 6 GeV tools
    - Measurement/match: 6-8 hours (expert) ➔ 1 hour (operators)

- Additional benefits
  - Matching more systematic and consistent through CEBAF
    - Driven by elegant CED/online model
  - Faster matching can be performed more routinely
  - "Parasitic" beam emittance data from every scan/rematch

MOPWI046 (D. Turner, config)
MOPWI045 (T. Larrieu, CED)

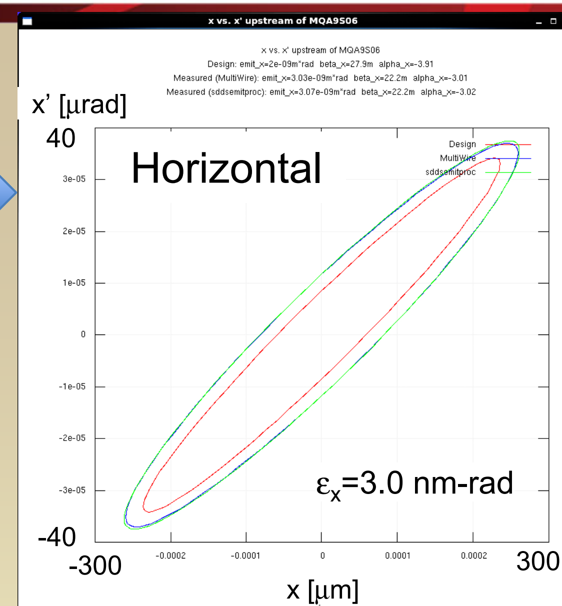
- Note following data is for 11 GeV CEBAF commissioning
  - Full 12 GeV commissioning in Fall 2015

Model-Based Optics Rematch



Before match, as found

After match



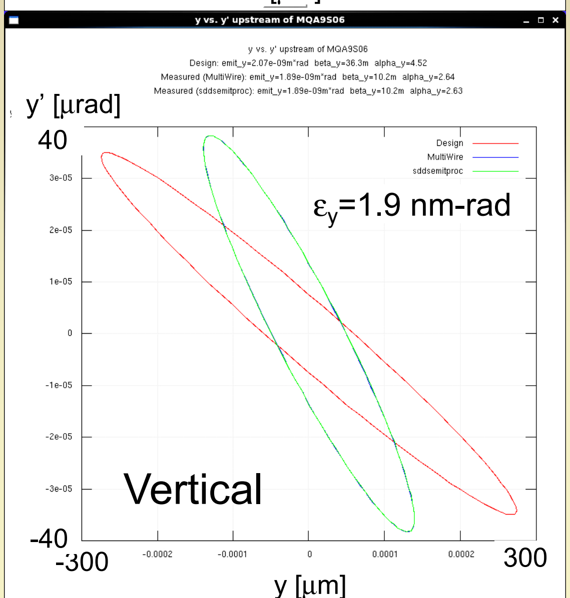
All data plotted is the projected beam ellipse in (x,x') at start of an upstream scanned quad

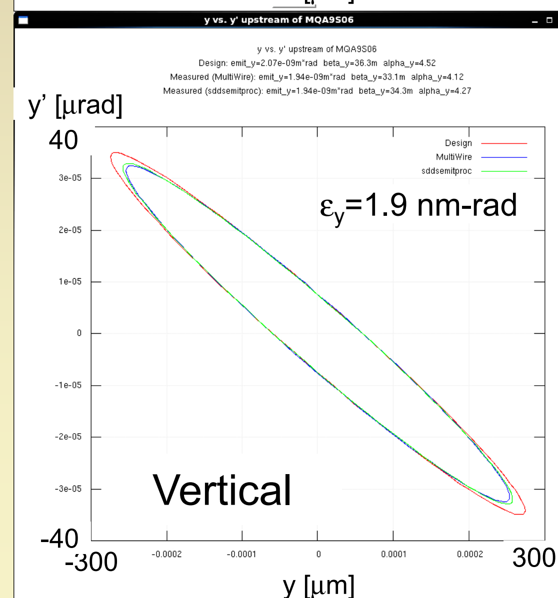
This data is for Arc 9 spreader

Blue and green ellipses are online model prediction

Red is measurement

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





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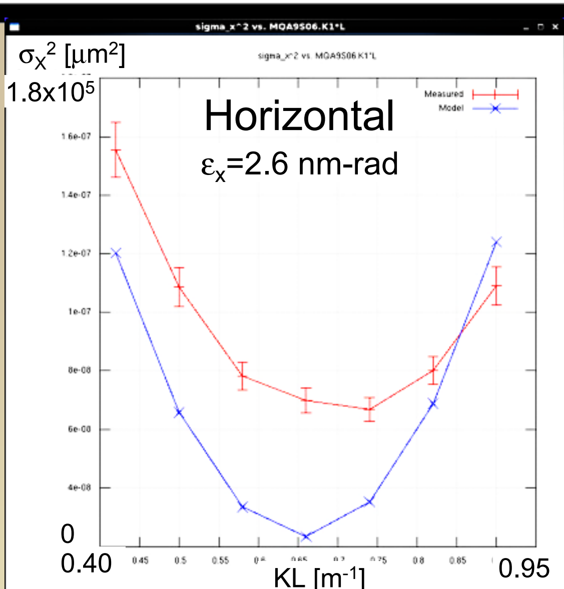
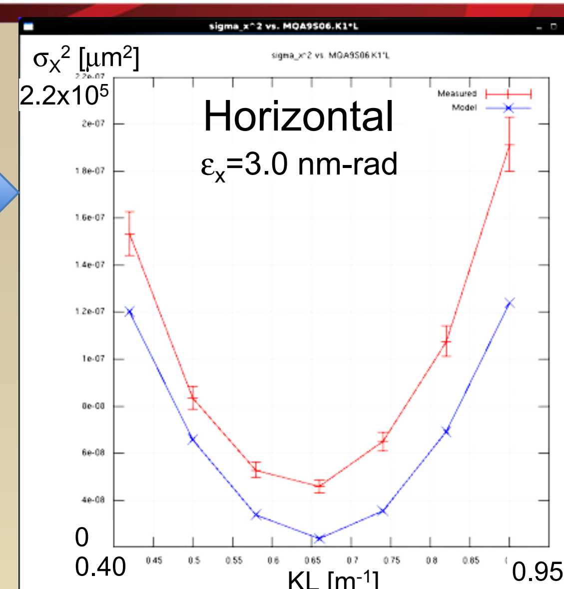


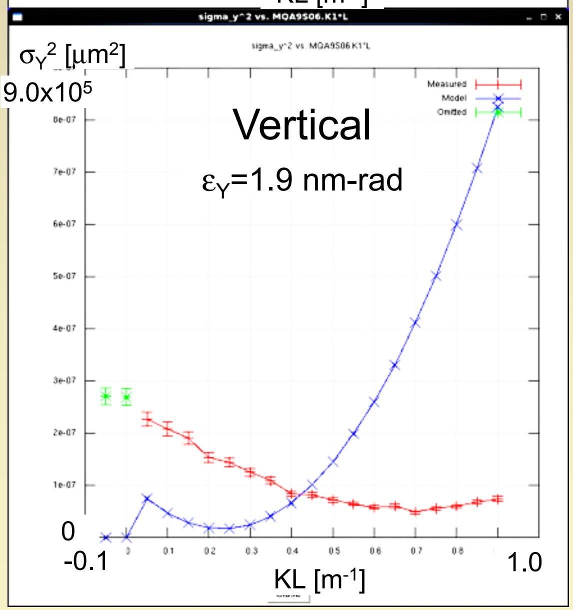
Before match, as found

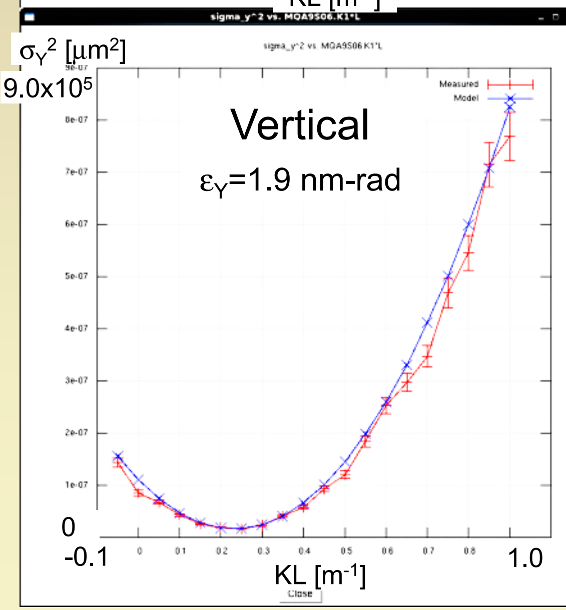
After match



All data plotted is

(measured beam σ_{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

Spring 2015 Measurements

	All geometric rms values, [nm-rad]			
Location	**Design ε_X**	**Meas ε_X**	**Design ε_Y**	**Meas ε_Y**
123 MeV	4.0	2.5±0.9	4.0	1.9±0.6
Arc 1	0.41	0.43±0.04	0.41	0.32±0.05
Arc 2	0.26	0.50±0.10	0.23	0.31±0.10
Arc 3	0.22	0.63±0.05	0.21	0.72±0.07
Arc 4	0.21	0.81±0.07	0.24	0.65±0.10
Arc 5	0.33	--	0.25	--
Arc 6	0.58	0.48±0.05	0.31	0.66±0.04
Arc 8	1.21	1.1±0.1	0.57	1.0±0.1
Arc 9	2.09	3.1±0.2	0.64	1.9±0.3
Arc 10	2.97	2.4±0.3	0.95	1.7±0.4

Wire scanner not installed in Arc 7 in spring 2015; reinstall for fall 2015
Wire scanner in Arc 5 in disrepair, to be repaired summer 2015

Future Plans

- Fall 2015: Full CEBAF 12 GeV commissioning
  - Evaluation of full impact of SR on transverse emittances
  - Improved matching procedures
  - Investigate/compare beams for different halls/lasers
  - Investigate/measure/reduce systematic errors

- Longer term improvements
  - Parasitic emittance monitoring with sync light monitors
  - Wire scanners ➔ large dynamic range YAG viewers / CTR
  - Iteration of model-driven machine
    - Optics measurements with LOCO, rayTrace

CSR Suppression Experiment

- 12 GeV CEBAF is a natural CSR/ISR test bed
  - Yves Roblin heading LDRD project to evaluate feasibility
- Jefferson Lab MEIC concept

TUYB3 (F. Lin et al., MEIC)

  - includes e-cooling from a high-power ERL (55 MeV, 200 mA)
  - recirculated beam quality critical: control CSR, μBI
- Leverage…
  - CSR emittance growth compensation lattice design
    - Recent ideas of diMitri/Cornacchia/Douglas/Borland

TUPMA034 (D. Douglas et al., CSR/ISR Control)

  - "High-current" gun (350 kV, 50-100 pC), compression to 0.5 ps
  - Extremes of ISR/CSR-driven emittance growth, energy spread

MOPMA025 (C.-Y. Tsai et al., CSR uB Transients)

Conclusions

- 12 GeV CEBAF transverse emittance dominated by synchrotron radiation in higher-pass arcs
  - (Somewhat) mitigated with FODO → DBA optics
- Optics matching and emittance program combined
  - Becoming efficient and mature
  - Excellent tool development
- Measurements, theory, simulations are consistent
  - Within factor of 2
  - 10.5 GeV data shows we are meeting program goals
  - Full 12 GeV commissioning in Fall 2015
- CSR mitigation experiments being developed

Thanks!

- Thank you to…
  - The CEBAF model team
  - The CEBAF beam transport “BTeam”
  - Yves Roblin, Dennis Turner, Arne Freyberger, Mike Spata, Mike Tiefenback, Alex Bogacz, Joe Grames, Chris Tennant, and REU student Charlie McIntyre (Reed College)
  - … and to you!