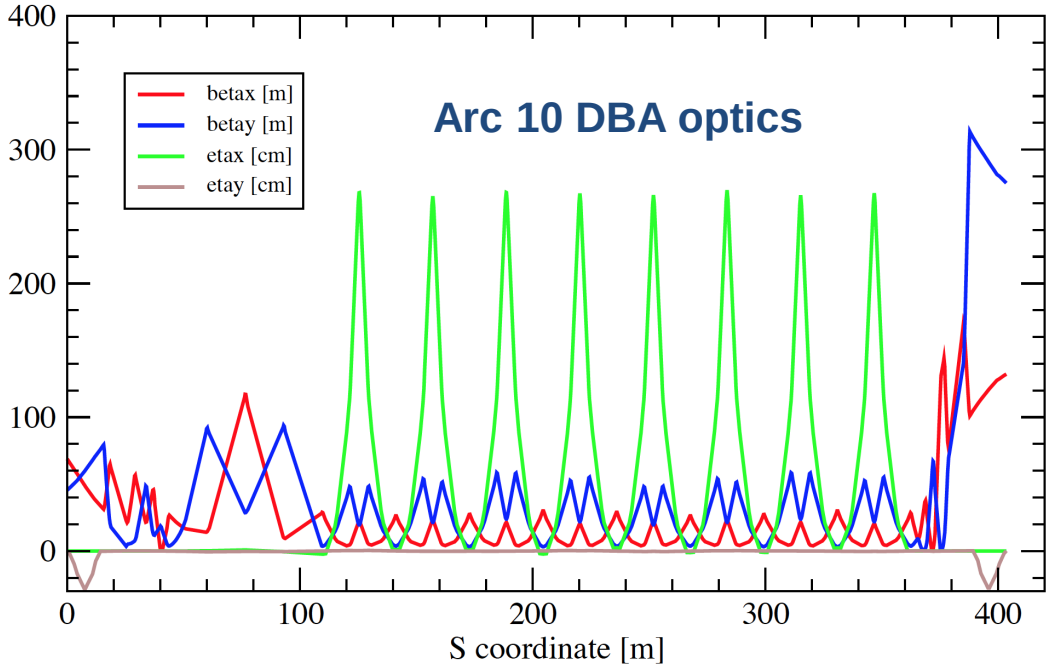
Synchrotron Radiation Emittance Growth

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

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

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	σ_p/p [x10^{-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

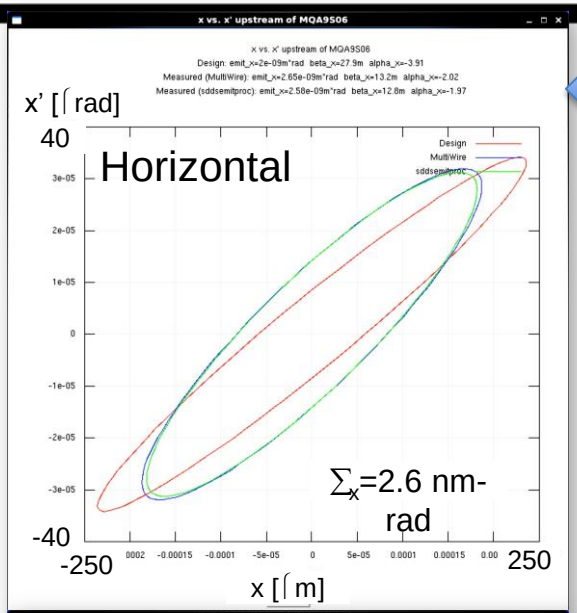
Emittance/Optics Campaign Strategy

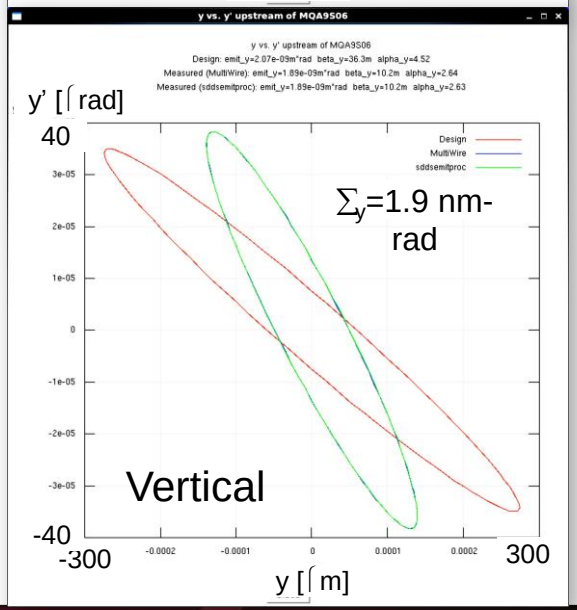
- Incorporated into **12 GeV optics commissioning**
  - Measure in all (available) matching regions
  - Single quad ➔ single wire scanner measurements
  - Improve automation, model integration in 6 GeV tools
    - Measurement/match: 6-8 hours (expert) ➔ 1 hour (operators)
    - See qsUtility talk from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

- Additional benefits
  - Matching more systematic and consistent through CEBAF
    - See earlier talk/discussion on ORFP betatron match strategy
  - Faster matching can be performed more routinely
  - “Parasitic” beam emittance data from every scan/rematch

- Note: following data is for 11 GeV CEBAF commissioning
- Full 12 GeV commissioning this fall will have similar strategy

Nice Model-Based Optics Rematch





Before match, as found

After match

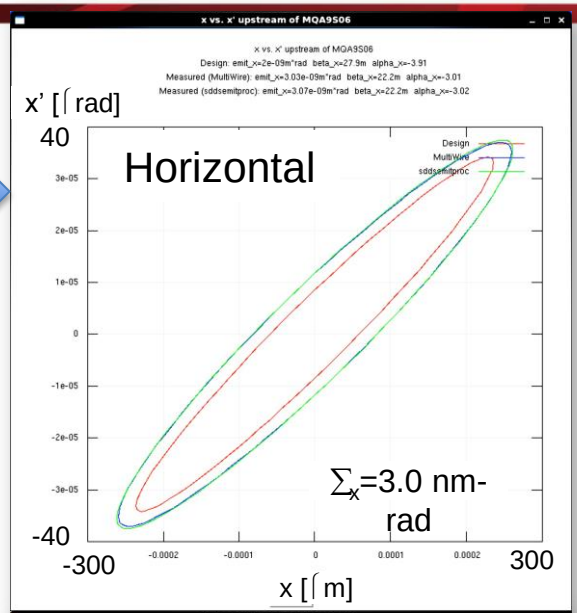
All data plotted is the projected beam ellipse in (x,x') at start of an upstream scanned quad

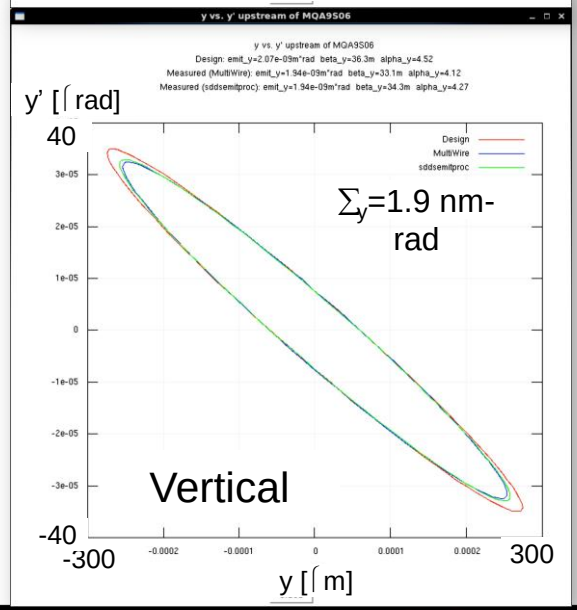
This data is for Arc 9 spreader

Blue and green ellipses are online model prediction

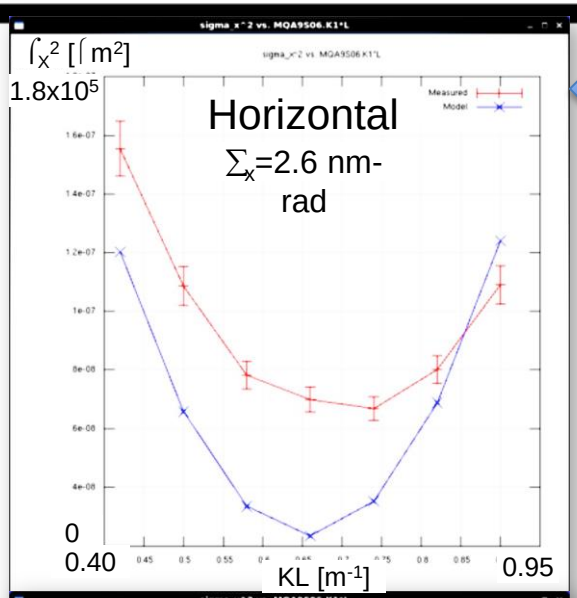
Red is measurement

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



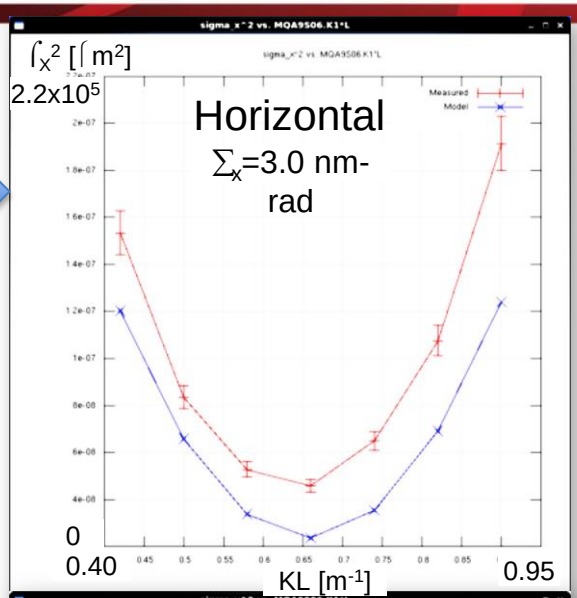


Nice Model-Based Optics Rematch



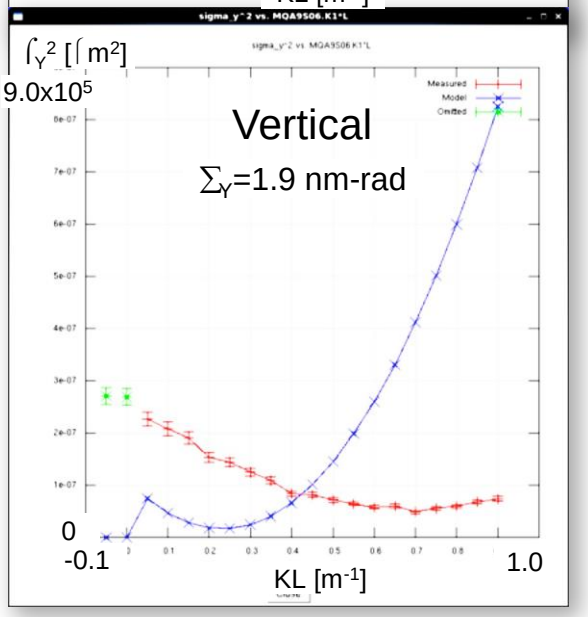
Before match, as found

After match



All data plotted is

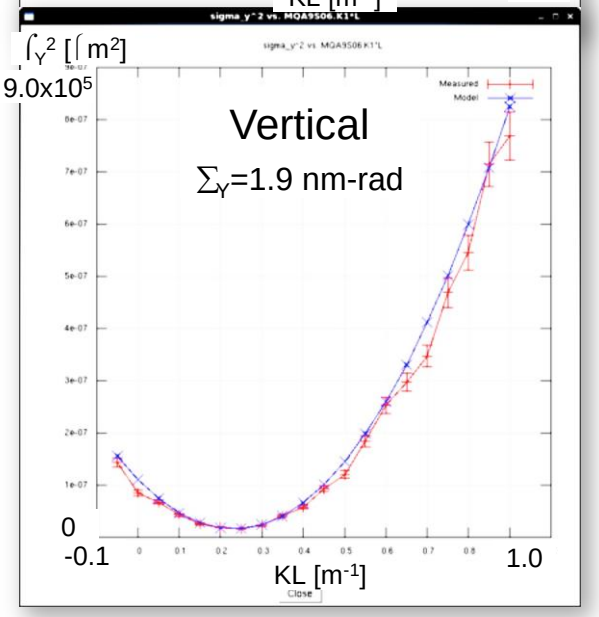
(measured beam $\int_{rms}$)^2
vs
(set quadrupole KL)



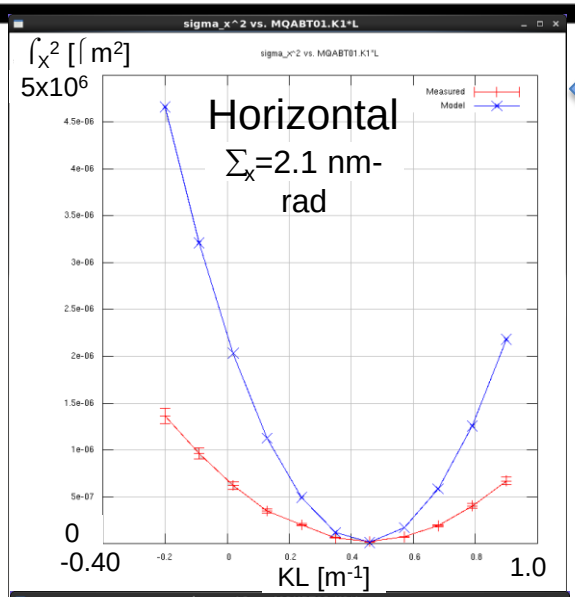
Blue data is model prediction

Red data is measurement

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

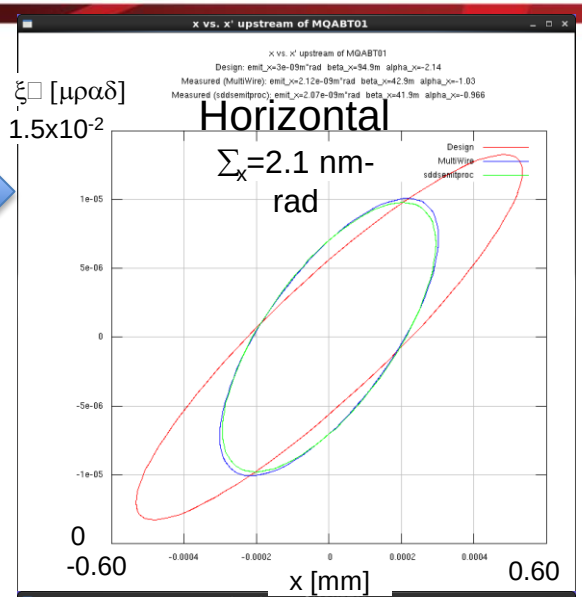


Typical Model-Based Optics Rematch



Sigma^2 vs K1L

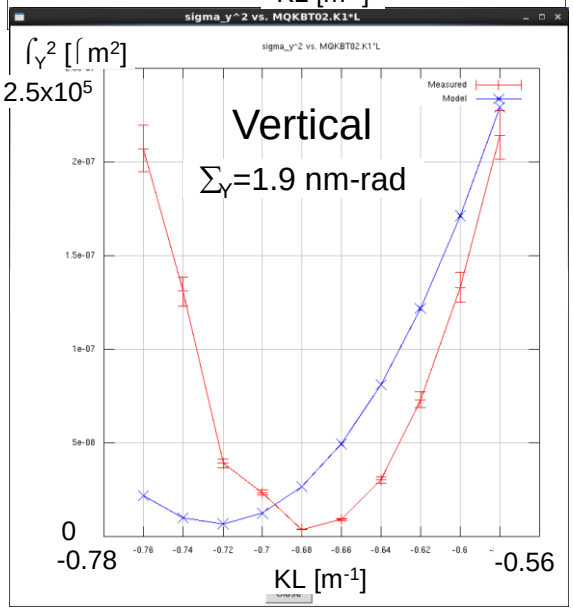
Beam Ellipse

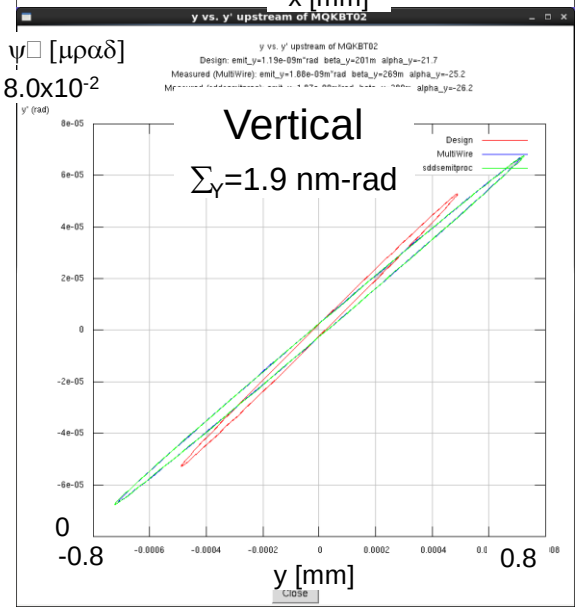


Blue data is model prediction
Red data is measurement

5C00 match -- Apr 23 2015 23:22:16
This still gave a good match!

Picked at random from elog using handy elog random search feature ☺





Recommendation: Adjust templates and scan quads so matches can be verified with additional scans, **and/or** modify qsUtility to construct model from live settings

Spring 2015 11 GeV Measurements

	All geometric rms values, [nm-rad]			
Location	**Design $\sum_X$**	**Meas $\sum_X$**	**Design $\sum_Y$**	**Meas $\sum_Y$**
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
Error bars are **only** measurement statistics, often over months

Documentation

- Optics spreadsheet in Google docs
  - Assembled/shared by Arne
- Procedures in detailed CASA Wiki area (with links)
  - https://casa.jlab.org/wiki/index.php/AP-CEBAF-Optics-2015-02-28
- Documentation used very well early in optics/matching/emittance campaign – what's there is very useful!
  - Wheels fell off with as run progressed
  - Wheels particularly fell off with cryo failure (and FMLA)
- Recommendations
  - Document last run in tech note (good practice for all beam studies)
  - Document next run optics campaign as above

CASA Wiki Snapshot

Procedure

- confirm harp is working and set harp parameters
- perform zigzag measurements to establish scan quadrupoles and ranges
- edit qsUtility configuration files if necessary
  - configuration files are in /a/opsdata/fiefdata/fileio/q/qsUtility/config/F3-0/GoldenTemplates
- perform qsUtility scans
- evaluate qsUtility data to get measured Twiss parameters and emittances
- back-propagate measured Twiss parameters to start of upstream xS04 quadrupole with elegant
  - A script to do this is in ~satogata/backpropagate.pl
- use qsUtility betatron match module to calculate xS04-xS10 match
  - configuration files are in /a/opsdata/fiefdata/fileio/q/qsUtility/match_config/F3-0
- evaluate and install match
- re-scan harp and evaluate match effectiveness
- After match is installed, one has to set the recombiner quads back to design in order to proceed to the next arc.
- perform confirmation fopt

Dynamic “procedure” for emittance campaign

Data and References

- Spring 2015 Optics Spreadsheet (Google docs)
- 0L injector match (E=107.2 MeV, BDL=536.365*K1 for L=0.15m magnets)
  - 0L07 H: zigzags -> MQD0L06 horizontal scan centered near 1800G, range +/-270G (BDL 3.35+/-0.5)
  - 0L08 V: zigzags -> MQB0L07 vertical scan centered near -3600G, range +/-500G (BDL -6.71+/-1.0)
  - Match calculation results and loading: e3322599 using C-laser, IHA0L07_2015-02-28_23:26 and IHA0L07_2015-03-01_00:01 datasets.
  - 2015-03-10 C laser after injector work, before 750 MHz separator work: horizontal analysis, horizontal analysis 2, vertical analysis, NL-inj match, horizontal analysis after match, and vertical analysis after match.
- 1E03 match (E=1057.2 MeV, BDL=5289.659*K1 for L=0.15m magnets, be careful MQN1S04 is L=0.30m, others are L=0.15m):
  - 1E03 H: zigzags -> MQB1E02 horizontal scan centered near 3100G, range +/-700G (BDL 0.586+/-0.133)
  - 1E03 V: zigzags -> MQB1E01 vertical scan centered near -2900G, range +/-1200G (BDL -0.548+/-0.227)
  - Analysis and match calculation: e3322630
  - Installed and confirmed match with fopt: e3322693 e3322695
- 2E01 match (E=2007.2 MeV, BDL=20085.89*K1 for L=0.30m magnets):
  - 2E01 H: zigzags zigzags -> MQC2S10 horizontal scan centered near 4600G, range +/-1000G (BDL 0.229+/-0.05)
  - 2E01 V: No zigzag solution found. Todd explored space with qsUtilityConfig and found reasonable scan of MQC2S08 K=-0.6 to 0.6 with MQC2S09 K=-0.1 m^-2 and MQC2S10 K=0.2 m^-2 (image)
  - In order to test that with the zigzag do the following (yves):

```
# caput MQC2S09.BDL -2009
# caput MQC2S10.BDL 4017
# scan_script.csh run IHA2E01 MQC2S08 Y 12051.000 -12051.000 9
```

Data, tricks, Elog links for analysis

Future Plans

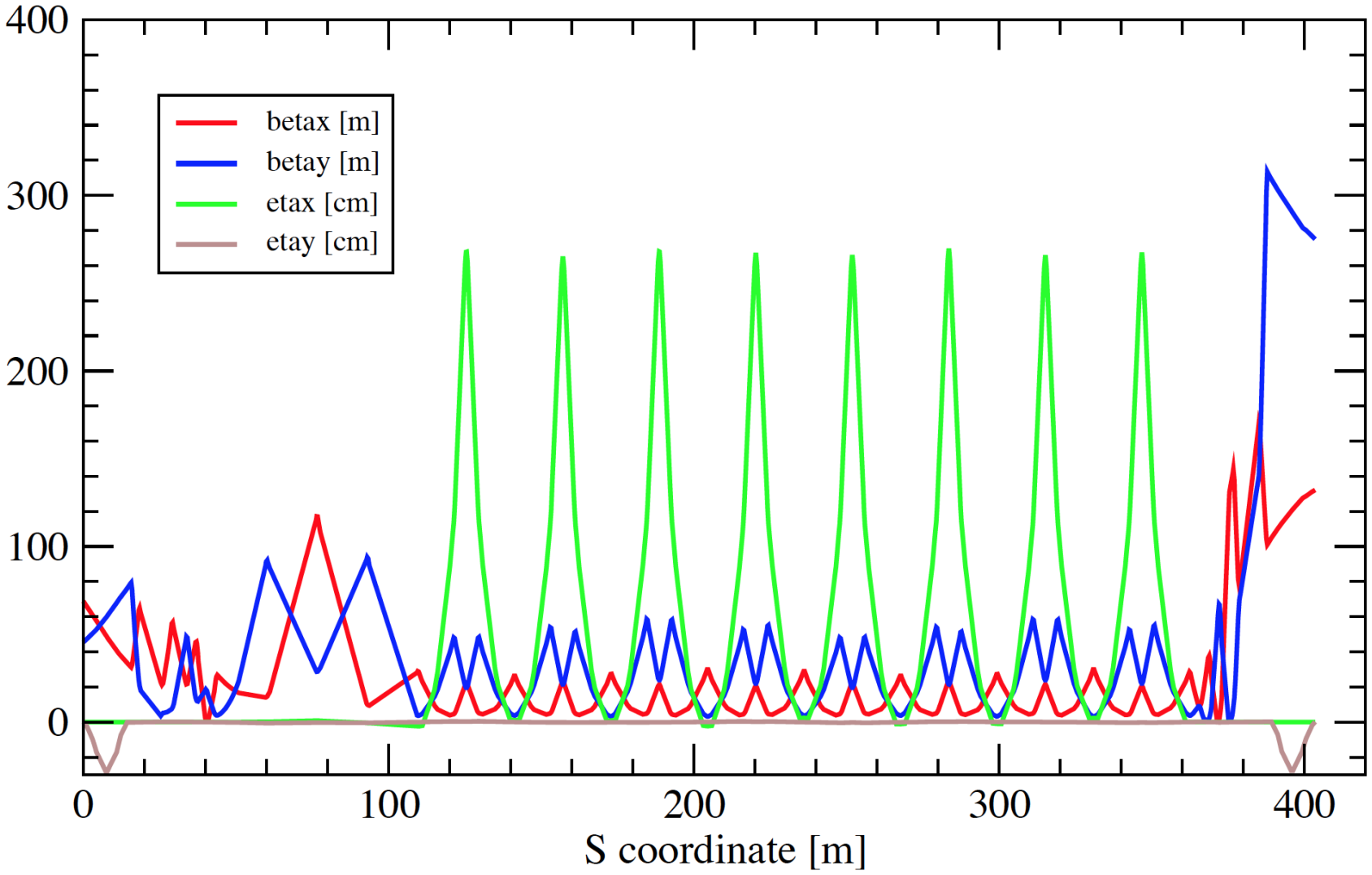
- Fall 2015: Full CEBAF 12 GeV commissioning
  - Evaluation of full impact of SR on transverse emittances
  - Improved matching procedures
  - Investigate/compare beams for different halls/lasers
  - Investigate/measure/reduce systematic errors

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

Summary

- 12 GeV CEBAF transverse emittance dominated by synchrotron radiation in higher-pass arcs
  - Was (somewhat) mitigated with FODO ➔ DBA optics
  - Will explore full impact with M_{56}=0 optics in Fall 2015
- Optics matching and emittance program combined
  - Becoming efficient and mature
  - Excellent tool development
- Measurements, theory, simulations are consistent
  - Within factor of 2(ish)
  - 10.5 GeV data shows we are meeting program goals
  - Full 12 GeV commissioning in Fall 2015

ARC 10 DBA Optics



ARC 1 M_{56}=0 Optics