JLab Accelerator Overview

CLAS Collaboration Meeting

Feb 23-26, 2016

Jefferson Lab

Michael Tiefenback, CASA

with grateful acknowledgment of material from others --
"Thank You" to all

Outline:

- Accelerator Operations
  - Summer 2015 -- Fall 2015
  - Outlook for Spring 2016 – Fall 2016
- SRF C100 controls improvements
  - energy jitter and vibration sensitivity
- Support for accelerator operations
  - CASA and Engineering/Diagnostics
  - Accelerator startup and operational tasks
  - Diagnostic systems and applications
  - Recent commissioning work/results
- Upcoming developments

Summer 2015: Final 12 GeV Preparations

12GeV Project related tasks:

Cryo	CHL2 Heat exchanger installation
Facilities	Arc tunnel air-conditioning.

OPS tasks:

Cryo	Repaired 2K cold box (SCM) via the SNS spare cold compressor.
DCpower	Dogleg upgrade.
RFpower&Software	750Mhz separator cavities.
SRF	Helium processing of the majority of CEBAF cavities.
IC&Software	Hall-D Fastback, nA BPMs

Utilities Infrastructure and Modernization (UIM) tasks:

Facilities	Upgraded cooling towers on accelerator site.

Fall2015 Goals:

- Systematic, deliberate, sequential machine setup at design energy.
  - Quad center every Quad-BPM combination with beam.
  - Minimize Arc orbit offsets, utilize the upgraded Dogleg system.
  - Beam matching at the entrance to each ARC.
- Establish 12 GeV CW beam operations to the Hall-D tagger vault.
- Measure beam parameters (ε, bunch length, TWISS parameters) at design energy.
- Evaluate energy reach, minimize trip rate.
- Establish 11 GeV separation, required to support 5^{th} pass separation of A/B/C beam simultaneously with beam to Hall-D.
- Establish high power CW operations to Hall-A at 11 GeV.
- **Establish the machine setup for Spring 2016 Physics program**

Gradient Distribution at 12 GeV

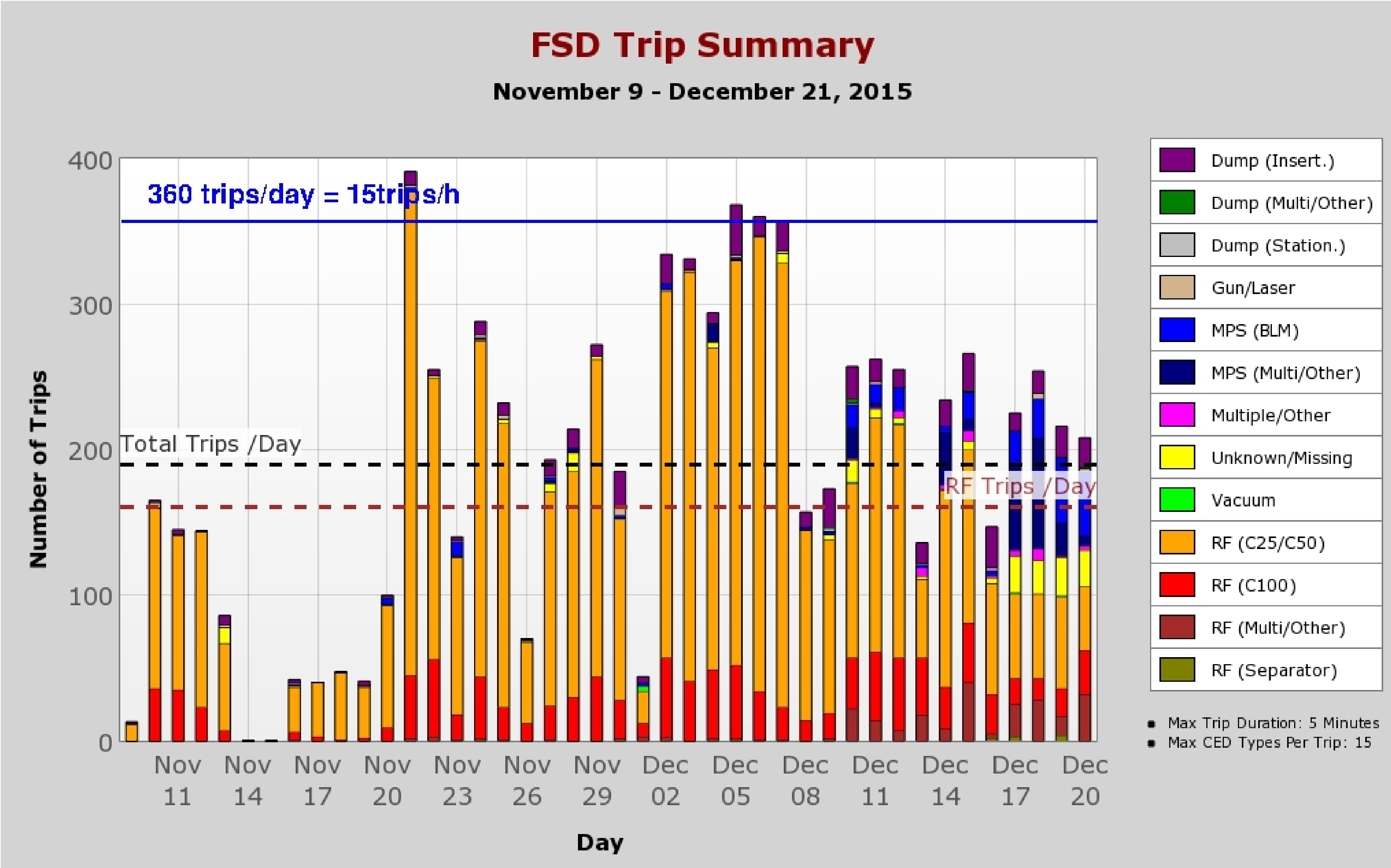
Dec 17 2015: RF trips < 5 trips/h

RF and arc1/arc2 status at: 2015-12-17 05:00

Linac	Type	Ncav	<GMES> (MV)	$GMES_{RMS}$ (MV)	Min-Max (MV)	Egain (MeV)
Inj	C20	8	8.24	2.15	4.96-11.02	33.0
Inj	C100	8	15.87	0.22	15.49-16.01	88.9
NL	C20	120	6.57	1.73	2.97-11.48	394.1
NL	C50	40	10.12	3.20	4.40-13.98	202.4
NL	C100	39	17.57	2.43	10.62-21.00	479.6
SL	C20	106	7.44	1.78	2.96-12.01	394.5
SL	C50	45	11.13	1.78	6.13-13.85	250.5
SL	C100	38	15.69	2.20	10.53-18.20	417.3

Linac	Egain (MeV)	Σ_E (MeV)	Spectrometer	Momentum (MeV/c)
Injector:	121.86	121.86	INJ:p	121.35
North Linac:	1076.04	1197.91	Arc1:p	1212.98
South Linac:	1062.35	2260.26	Arc2:p	2302.92

The Struggle: Trip Rate OK!



SRF C100 Improvements

- Cavity controls being updated to improve
  - Energy jitter
  - Vibration sensitivity
- Master Oscillator stability improved
  - Temperature stability, water flow control
  - Improvements in certain narrow-band disturbances (27Hz?)
- Collaborative work involves staff from many areas
- Significant improvements already seen
- More expected

Summer 2016

- Laser table upgrade to support 4-hall simultaneous running
- Install and commission C50-12
- Repair MYR6T02: Magnet coil leak. Found yesterday. No 3^{rd}-pass extraction until repaired.
- Low power bill operations
  - 1.1GeV/pass, 1-pass beam for Hall-B (PRad)
  - Injector Bubble Chamber engineering run
  - 1.1GeV/pass, 5-pass beam for Hall-C pre-checks

Summary

- 12 GeV CEBAF CW operations have been established.
  - Spring 2016 Physics program will be at the design energy.
- RF separation on 5^{th} pass (11 GeV) has been established.
  - Enables simultaneous Hall-D and A, B, or C operation on 5^{th} pass.
  - Presently limited to 3-hall operation, due to laser table configuration.
- Effort to improve CEBAF Reliability on-going.
  - Energy reach is a constant concern and requires vigilance.
  - A new cryomodule refurbishment program that provides 75MeV/cryomodule (C75) per year will increase the gradient margin.
  - CEBAF Downtimes are tracked and analyzed.
  - Performance data is used to develop near term fixes, annual work plans and long-term projects.
- Laser table upgrade planned for Summer 2016.
  - Four operations at design energy planned for Spring 2017.

CASA and CEBAF Operations

- CASA presently provides 2+ FTEs to CEBAF operations
  - Distributed among 6-7 participants
  - Commissioning support higher
- CEBAF Model Team
  - Optics model/lattice layout, design, controls integration
- Beam Transport Team (BTeam)
  - Operational review of tuning, optics, beam quality
  - Beam Studies forum
- Weekly optics on call rotation during CEBAF operations
  - Primary and backup opticians 24/7 for operations
  - Primarily for main accelerator transport retuning issues
    - e.g. diagnose beam jitter (identify subsystem support)
    - separate on-call support by injector and hall optics (APELs)

APELs

- **A**ccelerator **P**hysics **E**xperiment hall **L**iaisons
  - Hall A: Yves Roblin
  - Hall B: Michael Tiefenback
  - Hall C: Jay Benesch
  - Hall D: Todd Satogata
- Responsible for **beam delivery and hall integration**
  - Point person for hall beam tuning/beam quality every run
  - Evaluate/coordinate all hall experiment beam requirements
  - Design and improve beamlines/diagnostics/procedures
  - Works closely with similar liaison from Operations
  - Often a member of hall experiment collaborations

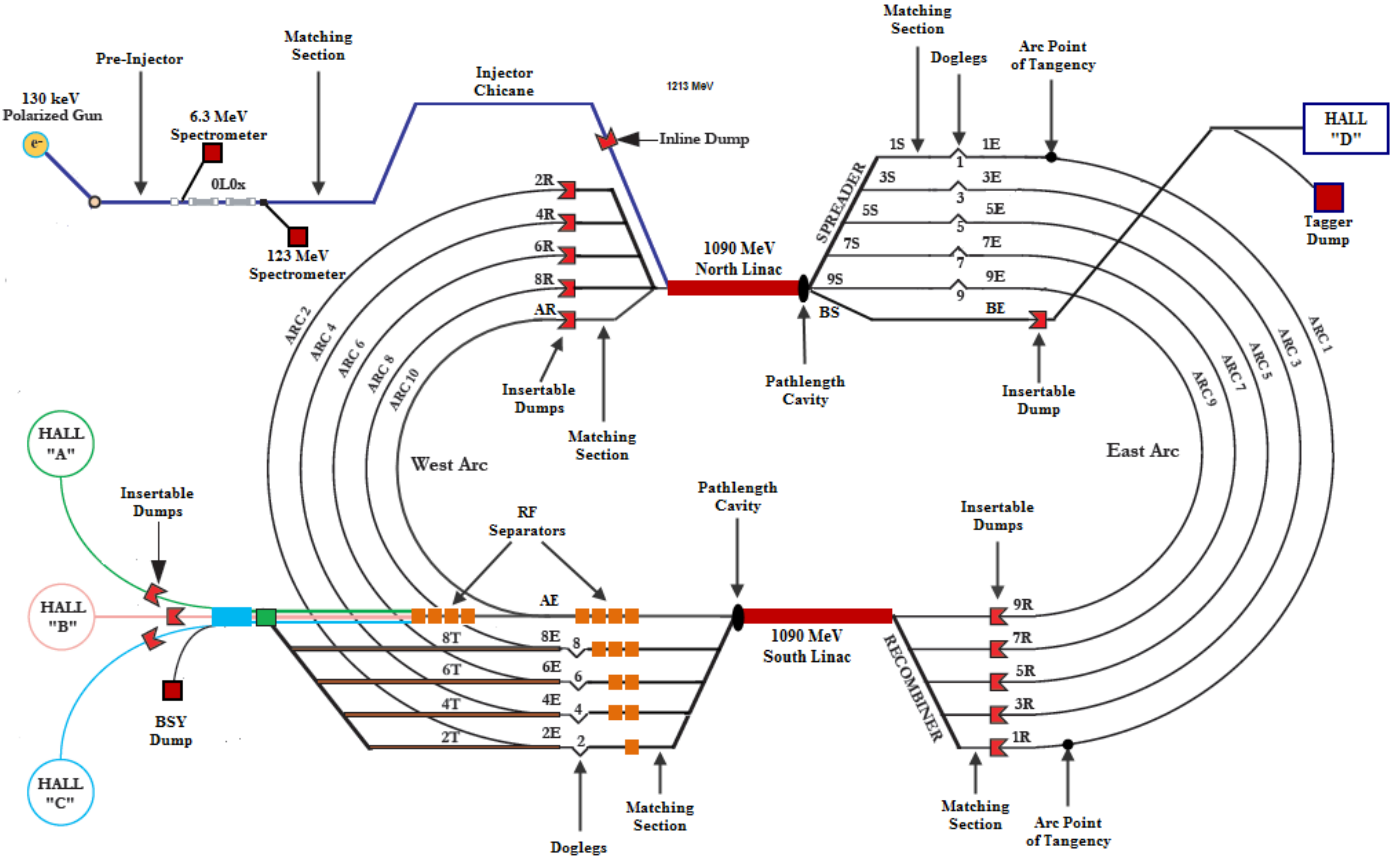
CEBAF 12 GeV Beam Physics

- CASA organized the detailed 12 GeV beam commissioning plan
  - Multi-year development plan
  - Successive beam diagnostics calibrations and measurements throughout
  - All CASA personnel engaged
  - Updates indicated progress through successive runs
  - Planned carefully
  - Performed as planned

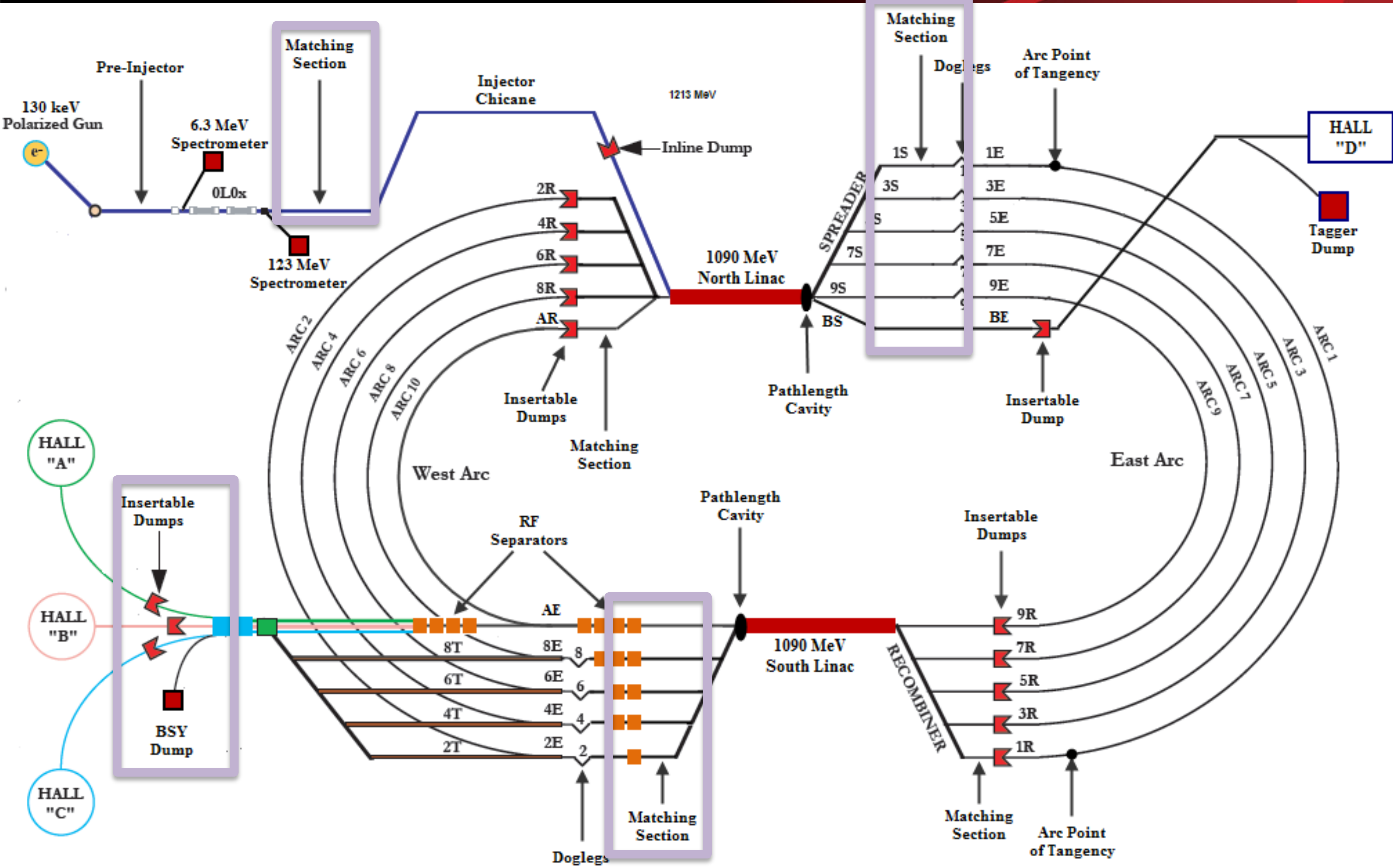
12 GeV Beam Commissioning Plan

Document Number: MCC-PR-01-010
Revision Number: Rev. 4; March 10, 2014
Technical Custodian: Michael Spata

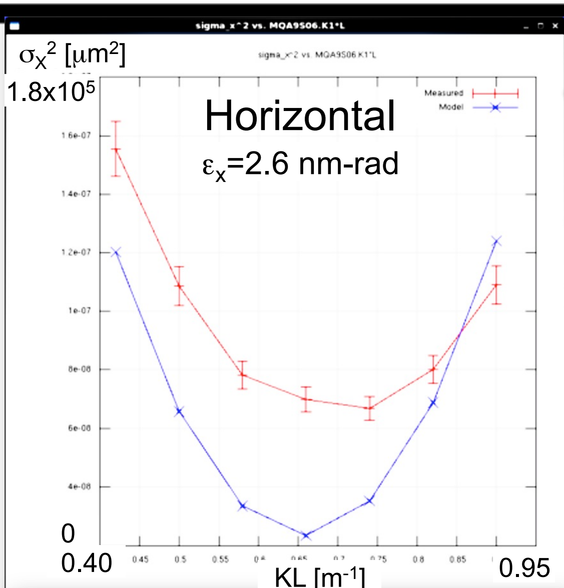
CEBAF Detail Schematic



CEBAF Detail: Transverse Matching

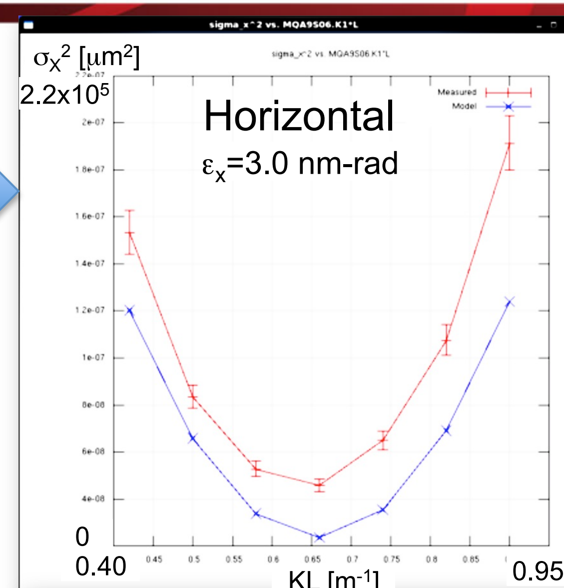


Model-Based Optics Rematch



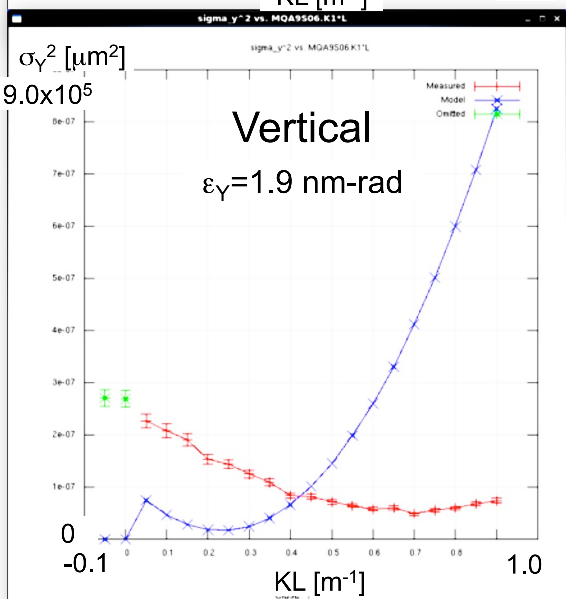
Before match, as found

After match



All data plotted is

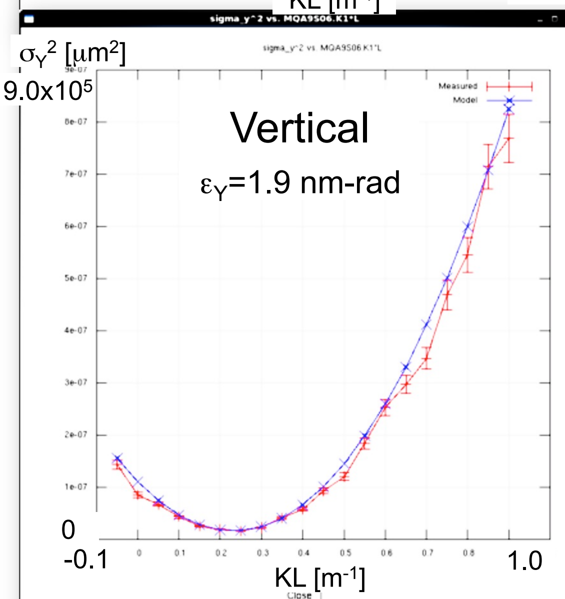
(measured beam σ_{rms})^2
vs
(set quadrupole KL)



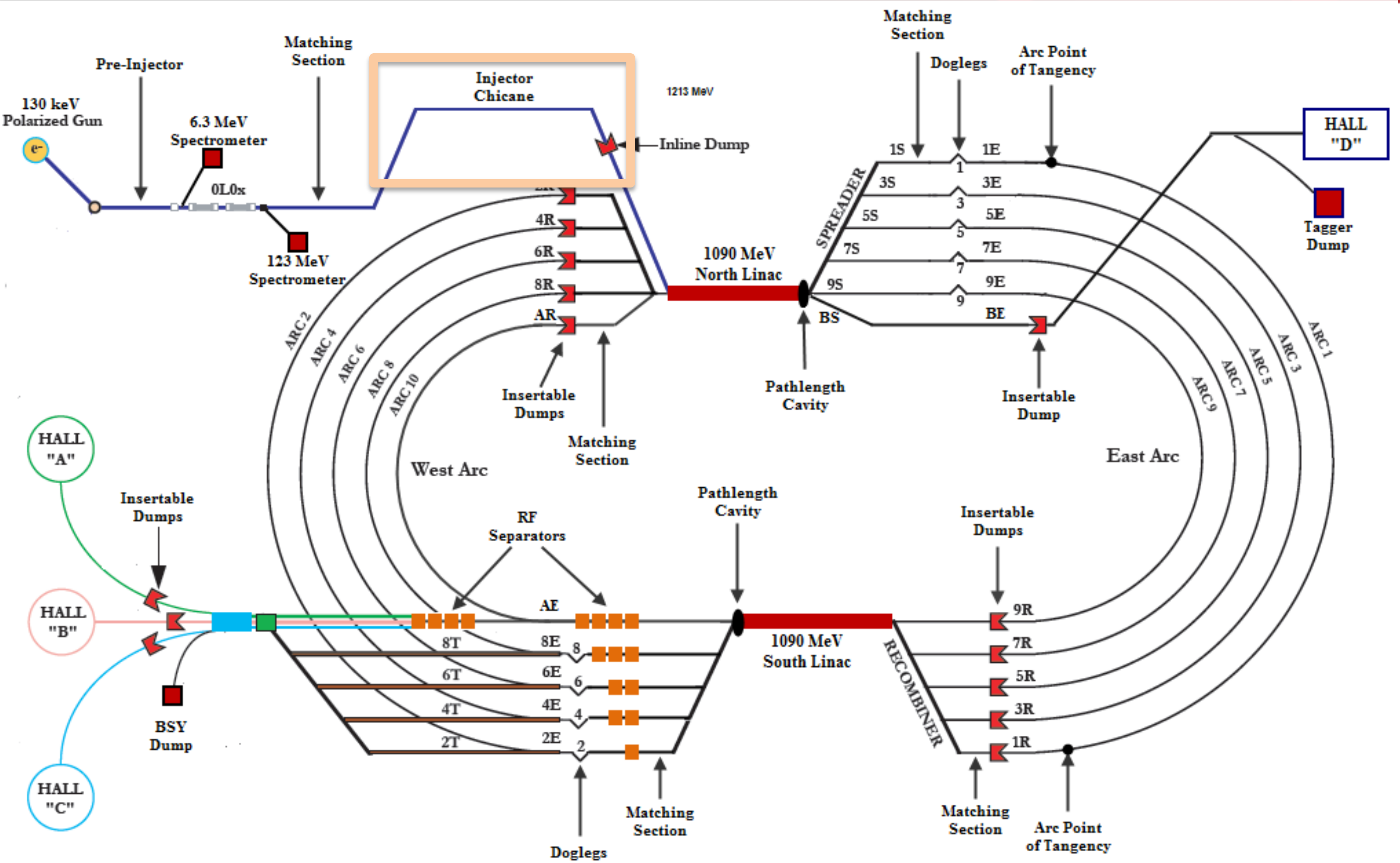
Blue data is design intent

Red data is measurement

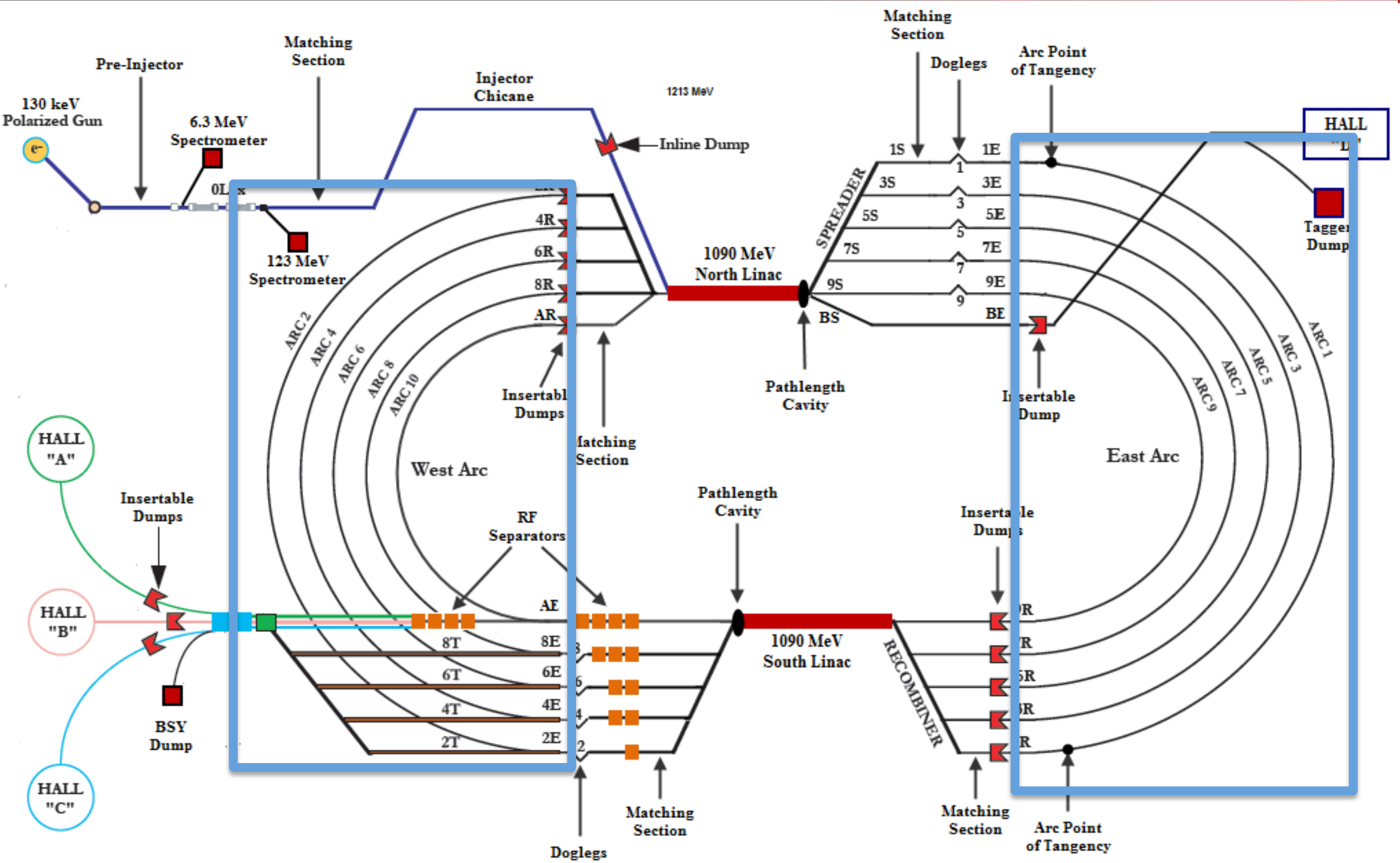
[Horizontal after-match variance is due to measured beam emittance being larger than design expectation]



CEBAF Detail: Bunch Length Compression



CEBAF Detail: Arc Transport and M_{56}



Initial Year's Beam Requirements

5.0 pass, 11GeV requirements

5.5 pass 12GeV

Hall	Emittance (nm-rad)	Energy Spread σ (%)	Spot Size σ (μm)	Halo
A	$\varepsilon_x < 10$ $\varepsilon_y < 5$	<0.05 (12 GeV) <0.003 (2-4 GeV)	$\sigma_x < 400$ $\sigma_y < 200$ $(\sigma_y < 100)$ (2-4 GeV)	$< 1 \times 10^{-4\dagger}$
B	$\varepsilon_x < 10$ $\varepsilon_y < 10$	<0.1	$\sigma_x < 400$ $\sigma_y < 400$	$< 2 \times 10^{-4\dagger}$
C	$\varepsilon_x < 10$ $\varepsilon_y < 10$	<0.05	$\sigma_x < 500$ $\sigma_y < 500$	$< 2 \times 10^{-4\dagger}$
D	$\varepsilon_x < 50$ $\varepsilon_y < 10$	<0.5	At Radiator: $\sigma_x < 1550$, $\sigma_y < 550$ At Collimator $\sigma_x < 540$, $\sigma_y < 520$	$< 1\%^{\ddagger}$

Physics beam requirements transmitted to CASA in 2007.

Initial Years Beam Requirements Met!

	Hall	Emittance (nm-rad)	Energy Spread σ (%)	Spot Size σ (μm)	Halo
5.0 pass, 11GeV requirements	**A**	$\varepsilon_x < 10$ $\varepsilon_y < 5$ ✔	<0.05 (12 GeV) <0.003 (2-4 GeV)	$\sigma_x < 400$ $\sigma_y < 200$ ✔ $(\sigma_y < 100)$ (2-4 GeV)	$< 1 \times 10^{-4\dagger}$
	B	$\varepsilon_x < 10$ $\varepsilon_y < 10$ ✔	<0.1	$\sigma_x < 400$ $\sigma_y < 400$ ✔	$< 2 \times 10^{-4\dagger}$ ✔
	C	$\varepsilon_x < 10$ $\varepsilon_y < 10$ ✔	<0.05	$\sigma_x < 500$ $\sigma_y < 500$ ✔	$< 2 \times 10^{-4\dagger}$
5.5 pass 12GeV	**D**	$\varepsilon_x < 50$ $\varepsilon_y < 10$ ✔	<0.5	At Radiator: $\sigma_x < 1550$, $\sigma_y < 550$ ✔ At Collimator $\sigma_x < 540$, $\sigma_y < 520$	$< 1\%^{\ddagger}$ ✔

Physics beam requirements transmitted to CASA in 2007.

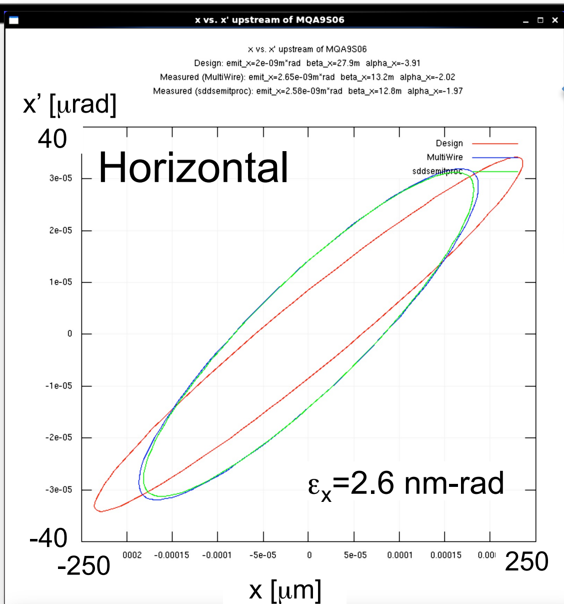
Emittance/Optics Campaign Strategy

- 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)

- Additional benefits
  - Matching more systematic and consistent through CEBAF
  - Faster measurements can be performed more routinely
    - e.g. comparison of different lasers, space charge effects
  - "Parasitic" beam emittance data from every scan/rematch

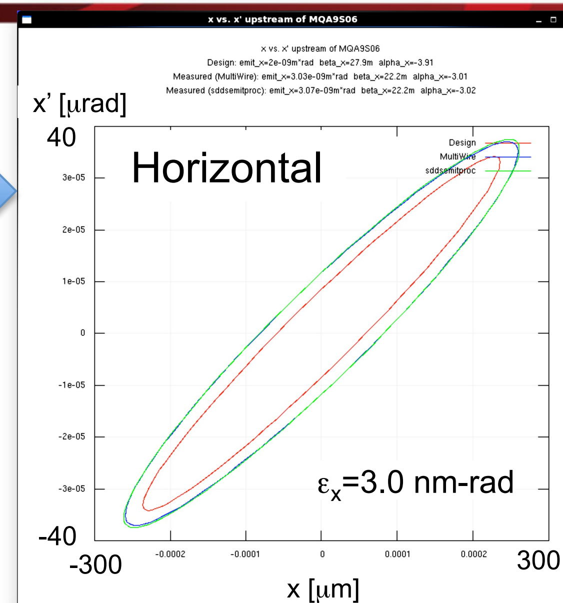
- 12 GeV data shown: Fall 2015-present

Model-Based Optics Rematch



Before match, as found

After match



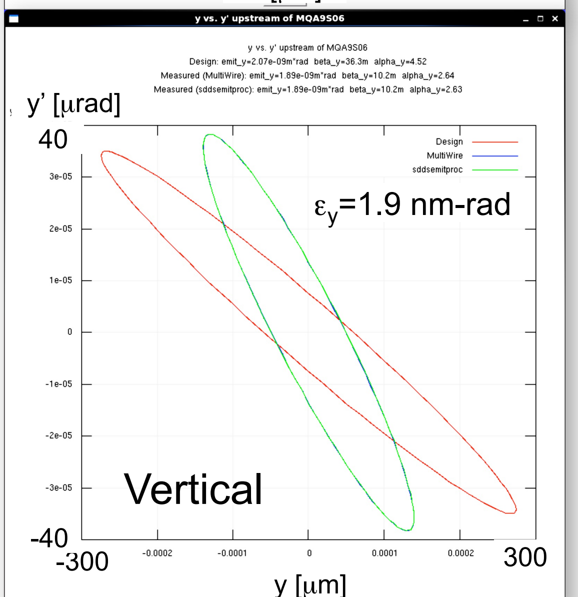
All data plotted is the projected beam ellipse in (x,x') at start of an upstream scanned quad

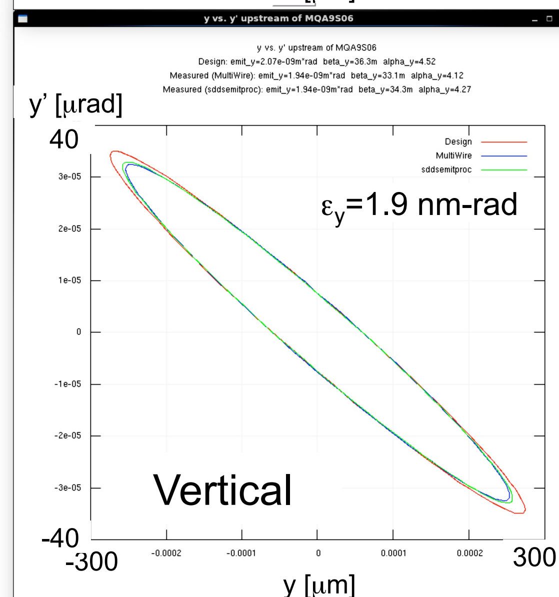
This data is for Arc 9 spreader

Blue and green ellipses are measurement

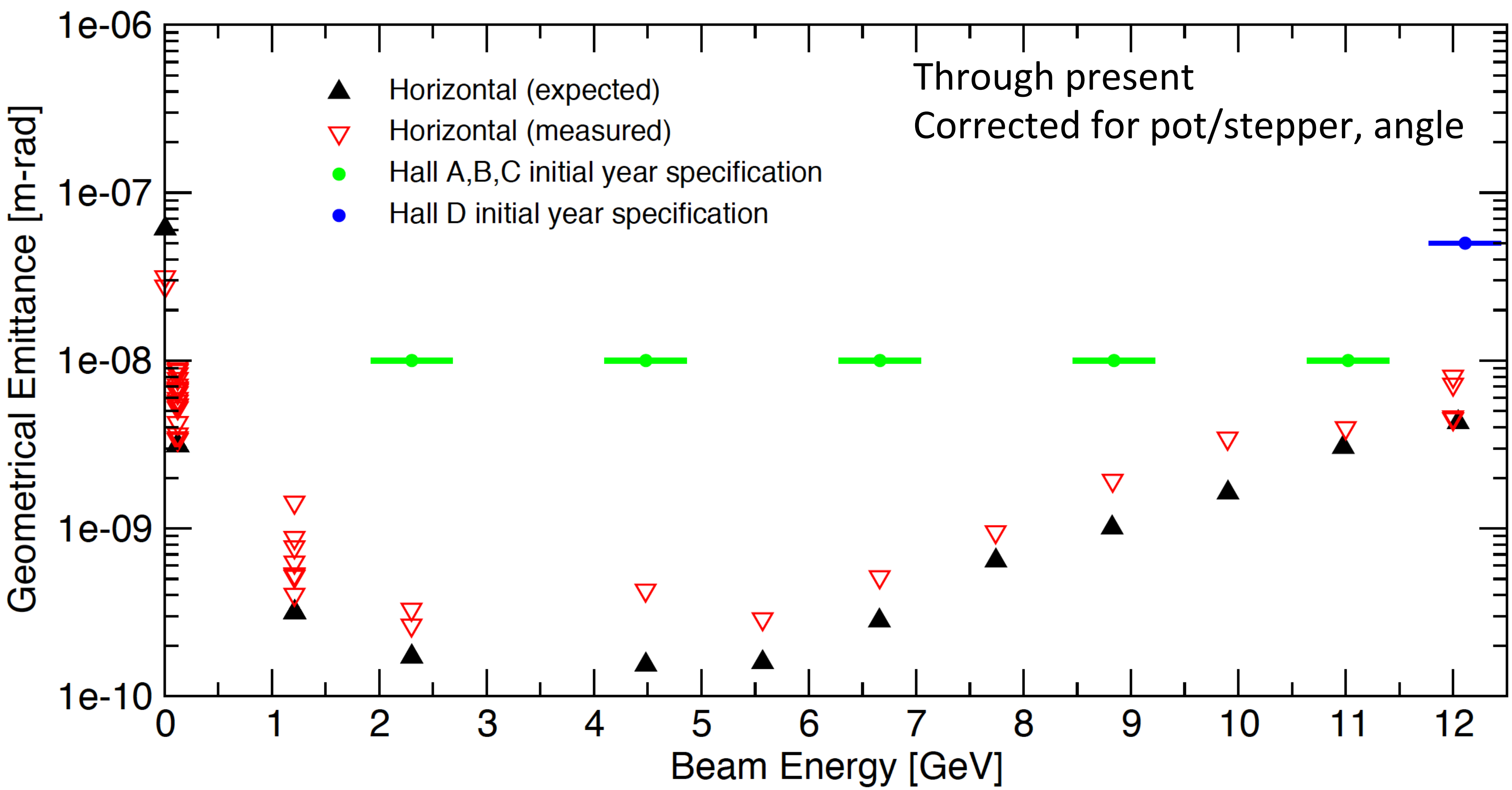
Red is online model prediction

Excellent agreement



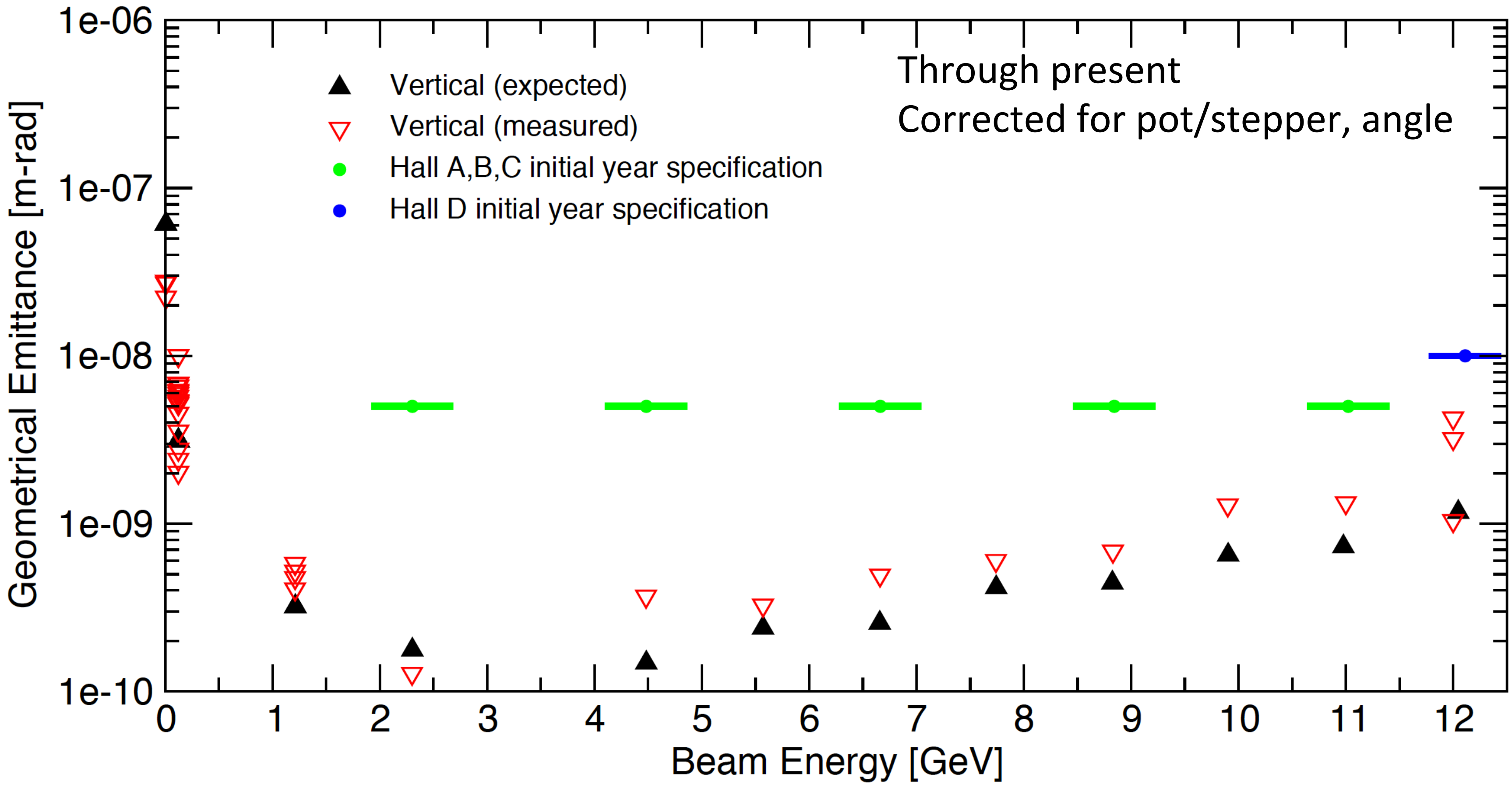


12 GeV Horizontal Emittances



- Horizontal emittances within all specifications
  - Usually within factor of two of design (often better)
  - Synchrotron radiation-driven emittance growth as predicted

12 GeV Vertical Emittances



- Vertical emittances also within all specifications
  - Synchrotron radiation-driven emittance growth also as predicted

Emittance Observations

- Detailed **top-to-bottom error analysis** in progress
  - Randoms: harp noise, carriage jitter, magnet regulation
  - Systematics: **harp scaling**, magnet transport, procedural clarity
- Randoms are small (~few %) vs potential systematics
- Observed large uncertainties in harp carriage transport scaling (up to 50%)
  - Miscalibration of linear potentiometer vs stepper travel
  - Contributes quadratically to calculated emittance
  - Does not substantially alter match parameters
  - Data shown includes pot/stepper angle correction
- **Quantify/cross-calibrate with non-blooming viewers**

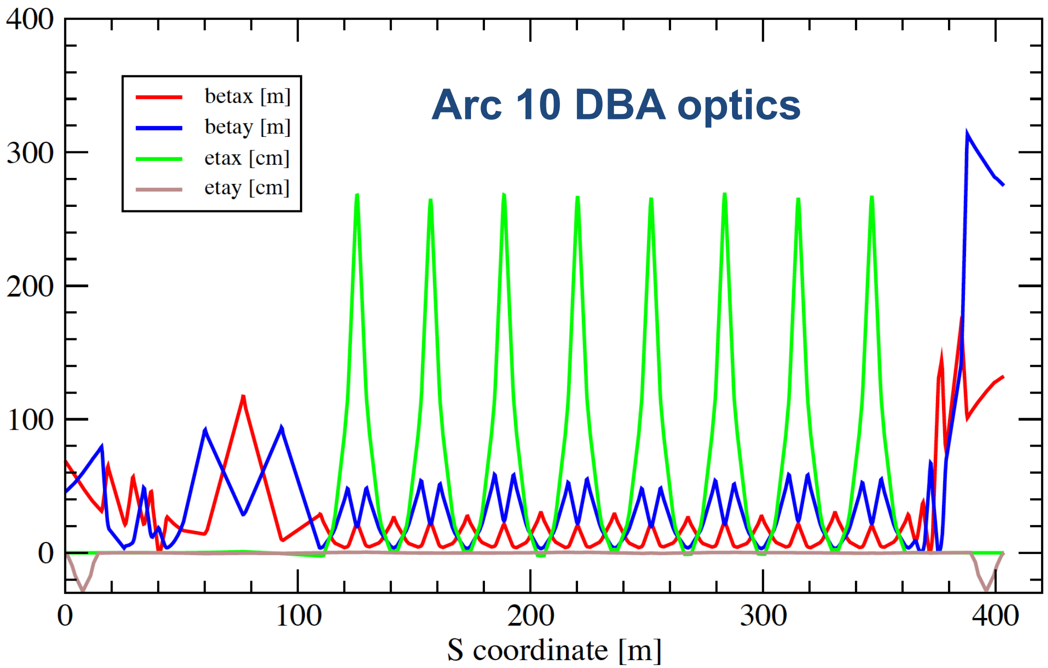
Emittance Growth Scaling and Mitigation

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

rms, geometric
180° multi-cell bend

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

Sands 1985, Douglas 1997

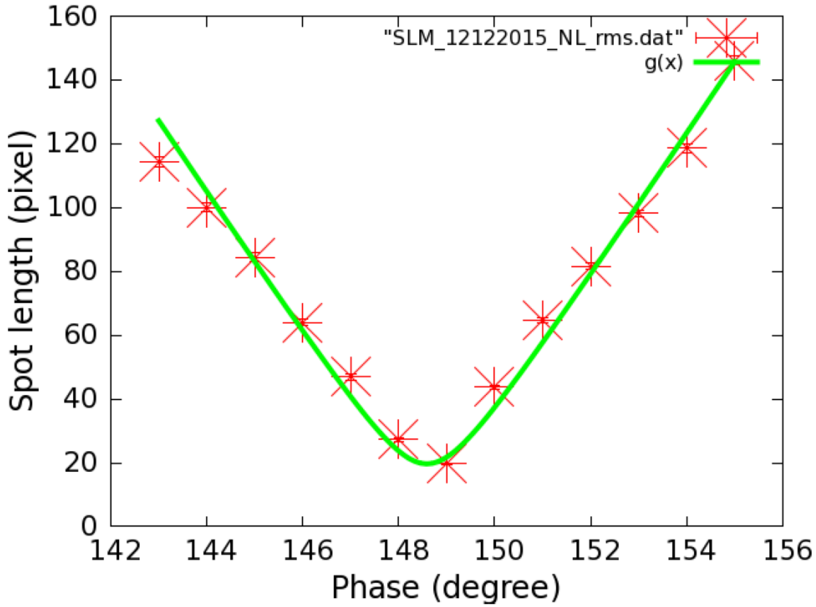


- Arc focusing very flexible: separate power supplies for all 32 arc quads
- Traditional CEBAF FODO cells ➔ DBA cells in higher arcs
- **30-40%** reduction in $\langle\mathcal{H}\rangle$
- **Tested in 2013-2014 11 GeV**
  - Dispersion/pathlength coupling through M_{56}

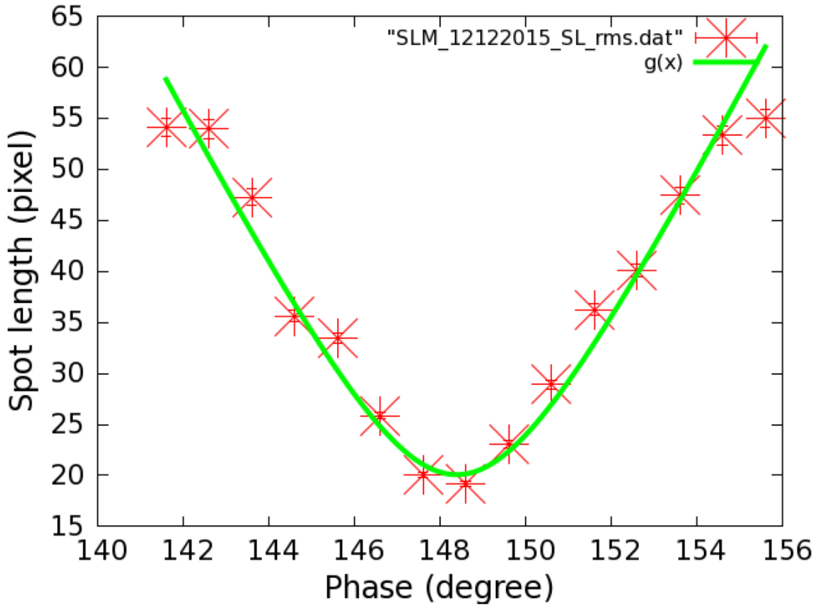
Bunch Length Measurements

M. Ahmad
PhD Student

Arc 1: $\sigma_l = 141\mu\text{m}$
$\sigma_t = 470\text{fs}$
$\sigma_{\phi(1497Mhz)} = \frac{1}{4}^{\circ}$

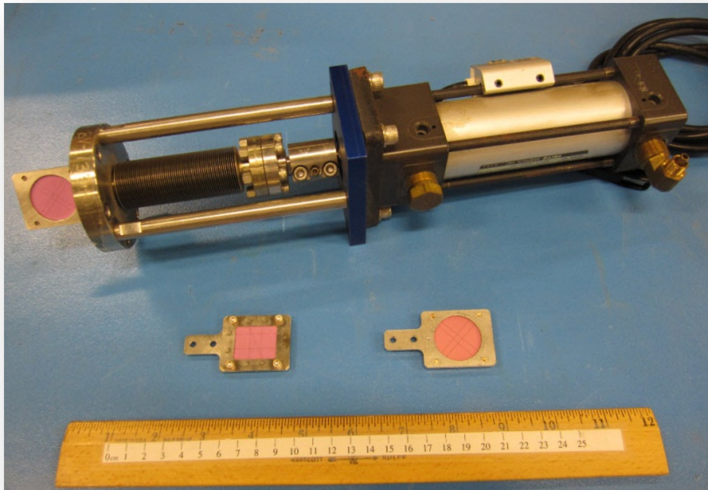


Arc 2: $\sigma_l = 144\mu m$
$\sigma_t = 480\text{fs}$
$\sigma_{\phi(1497Mhz)} = 0.26^{\circ}$

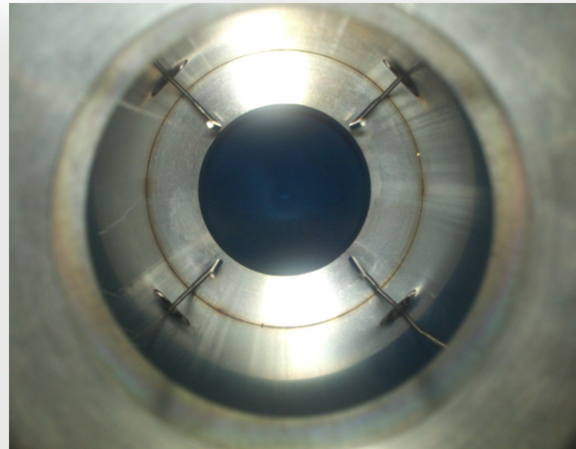


- Linac gang phase vs SLM dispersive bunch size
- Short bunches even without injector compression
  - Limit nonlinear halo, momentum spread in lower passes

6 GeV Existing Diagnostics

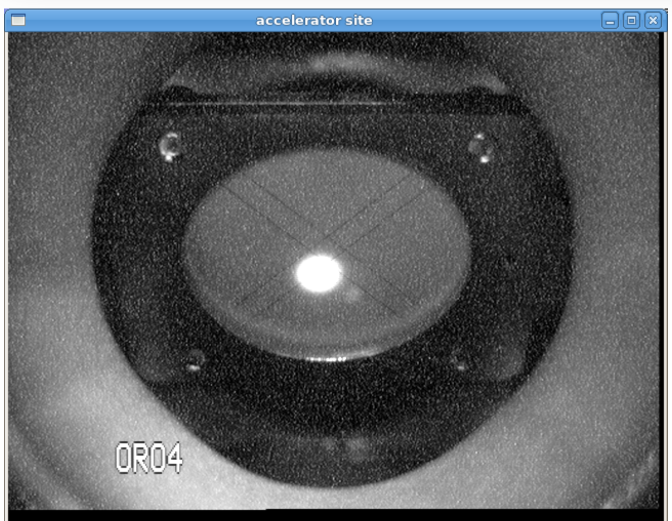


Beam Viewers

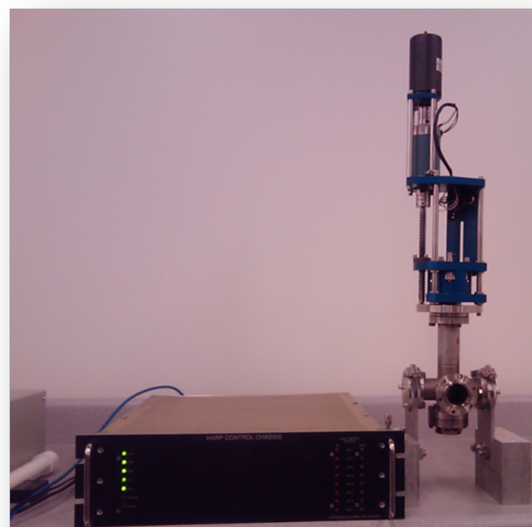


Antenna-Style Beam Position Monitor

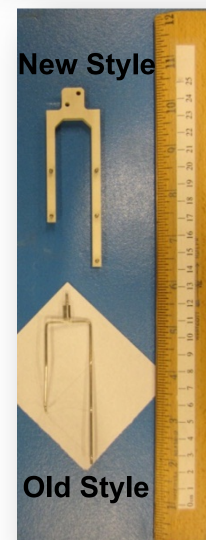
Pathlength Cavity



Beam on Viewer in Chicane

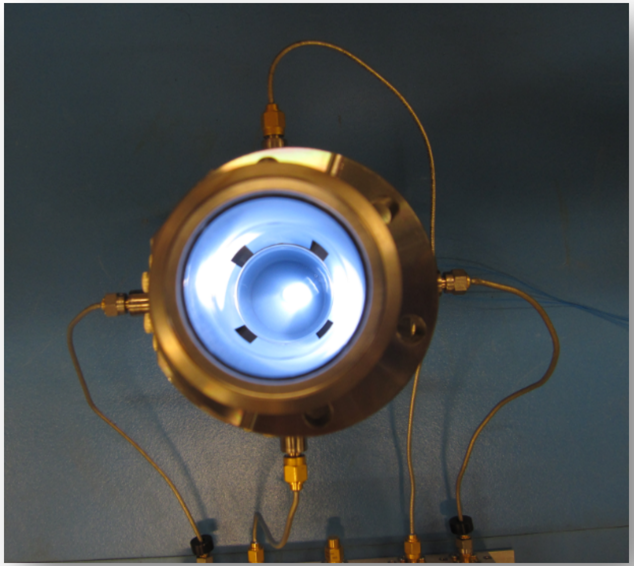


Wire Scanner and Electronics



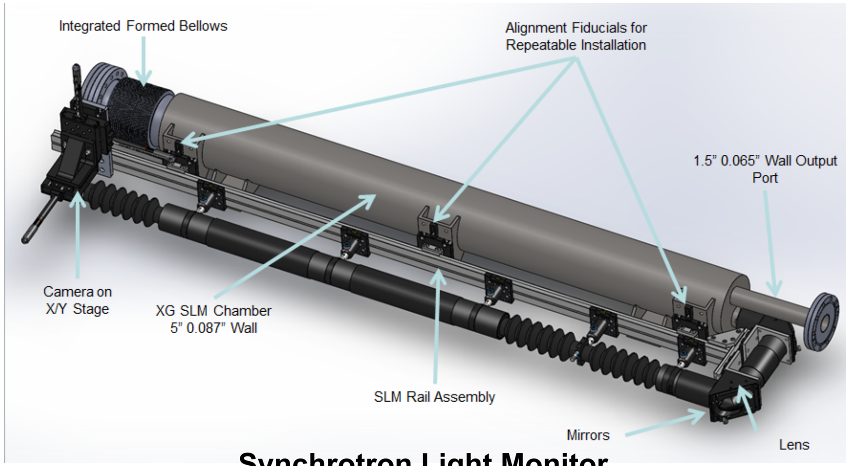
Wire Scanner Forks

New 12 GeV Diagnostics

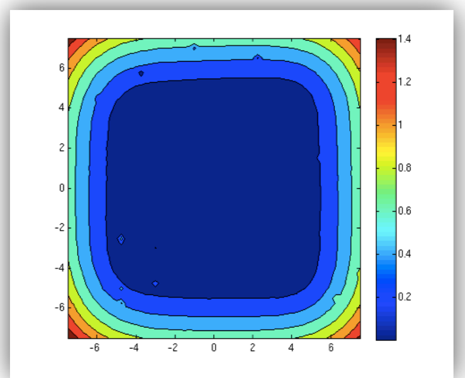


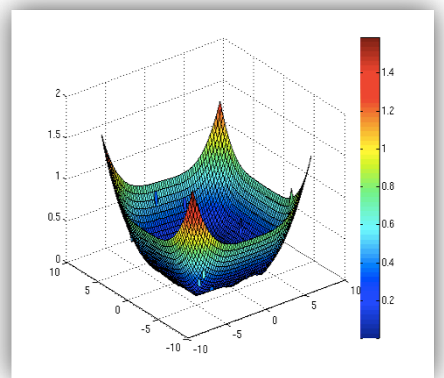
Stripline Beam Position Monitor

Stripline BPM on Stretched-Wire Test Stand



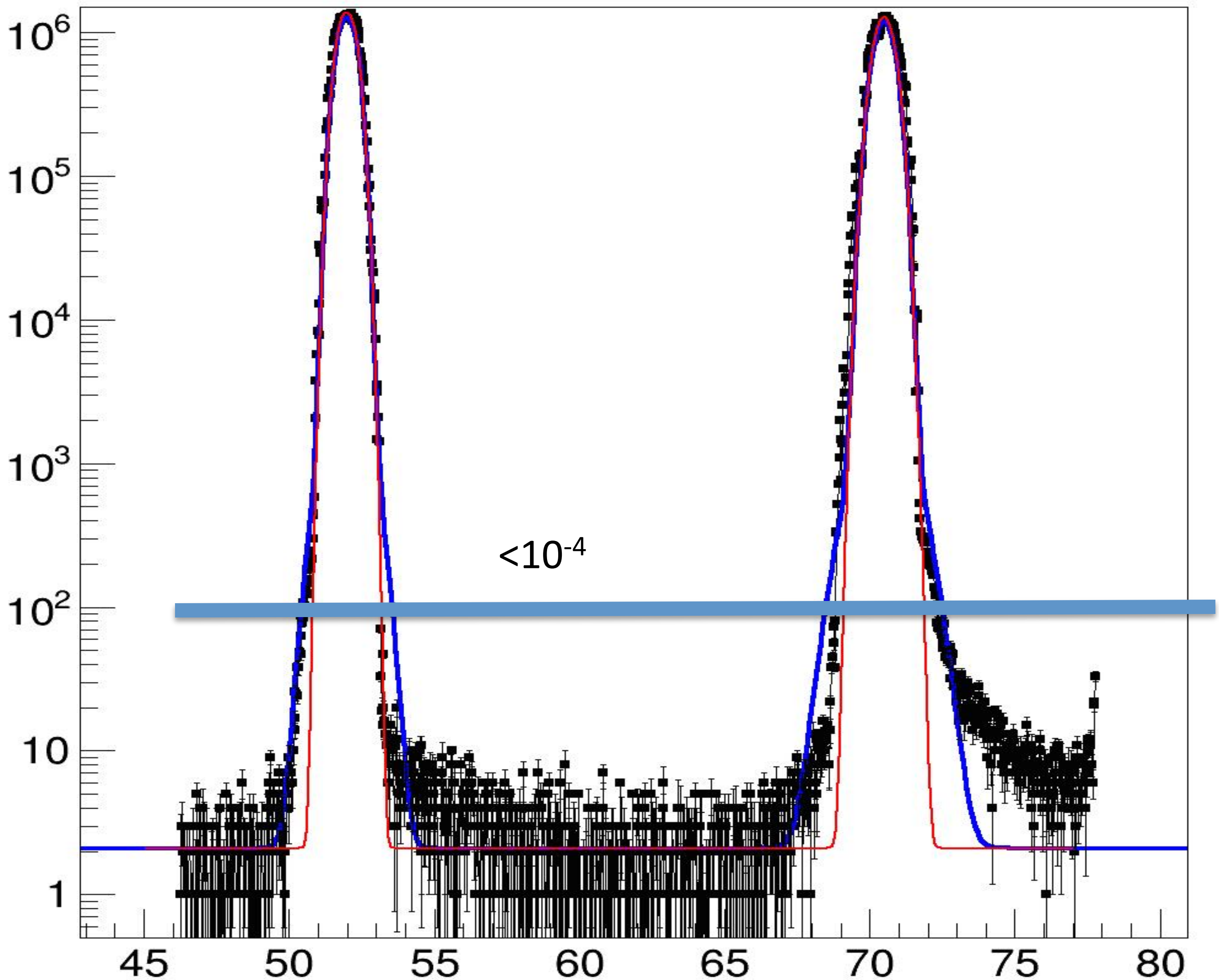
Synchrotron Light Monitor





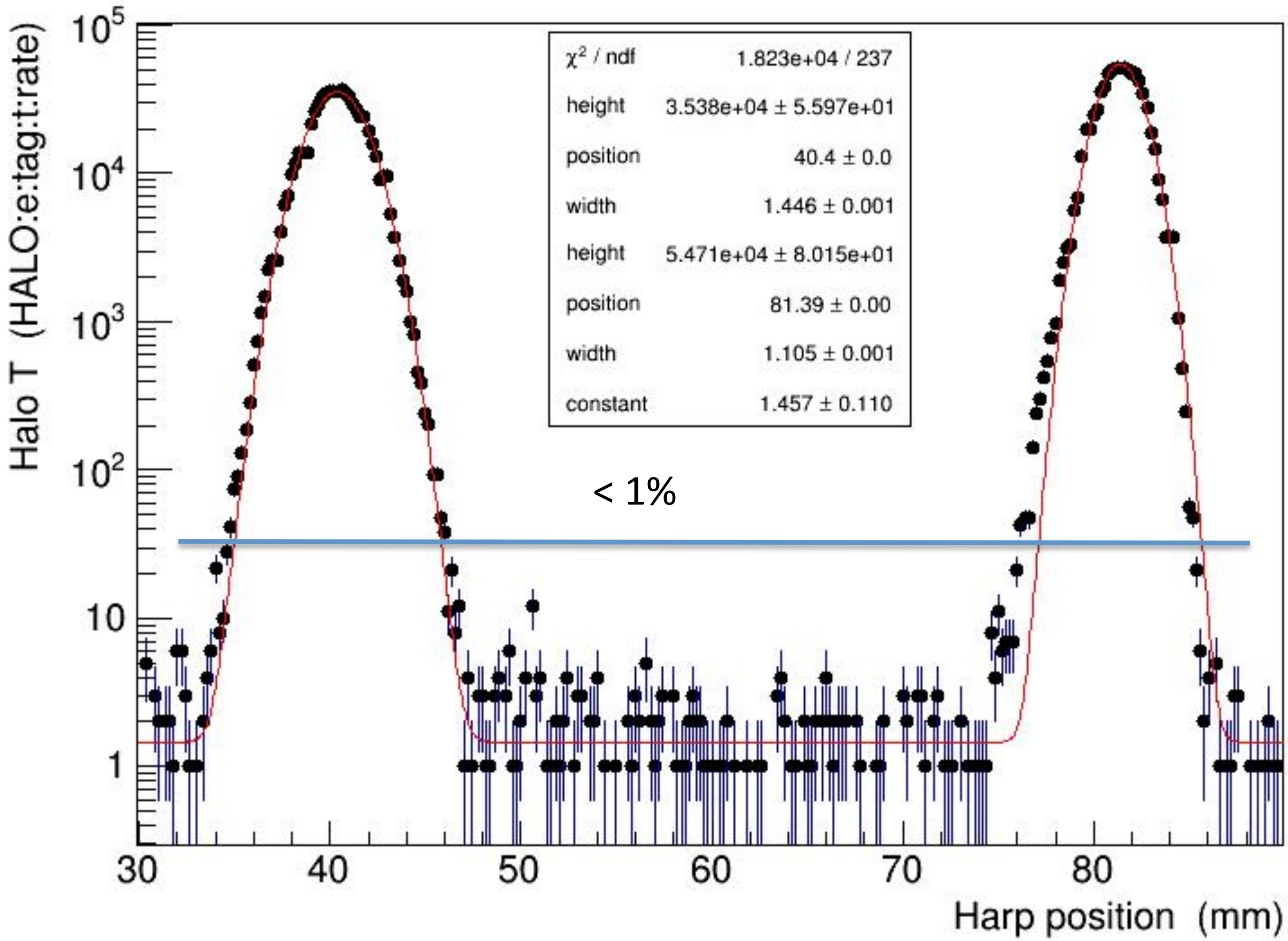
Typical Results from BPM Test Stand

Hall B: 1-pass Halo (1 GeV)



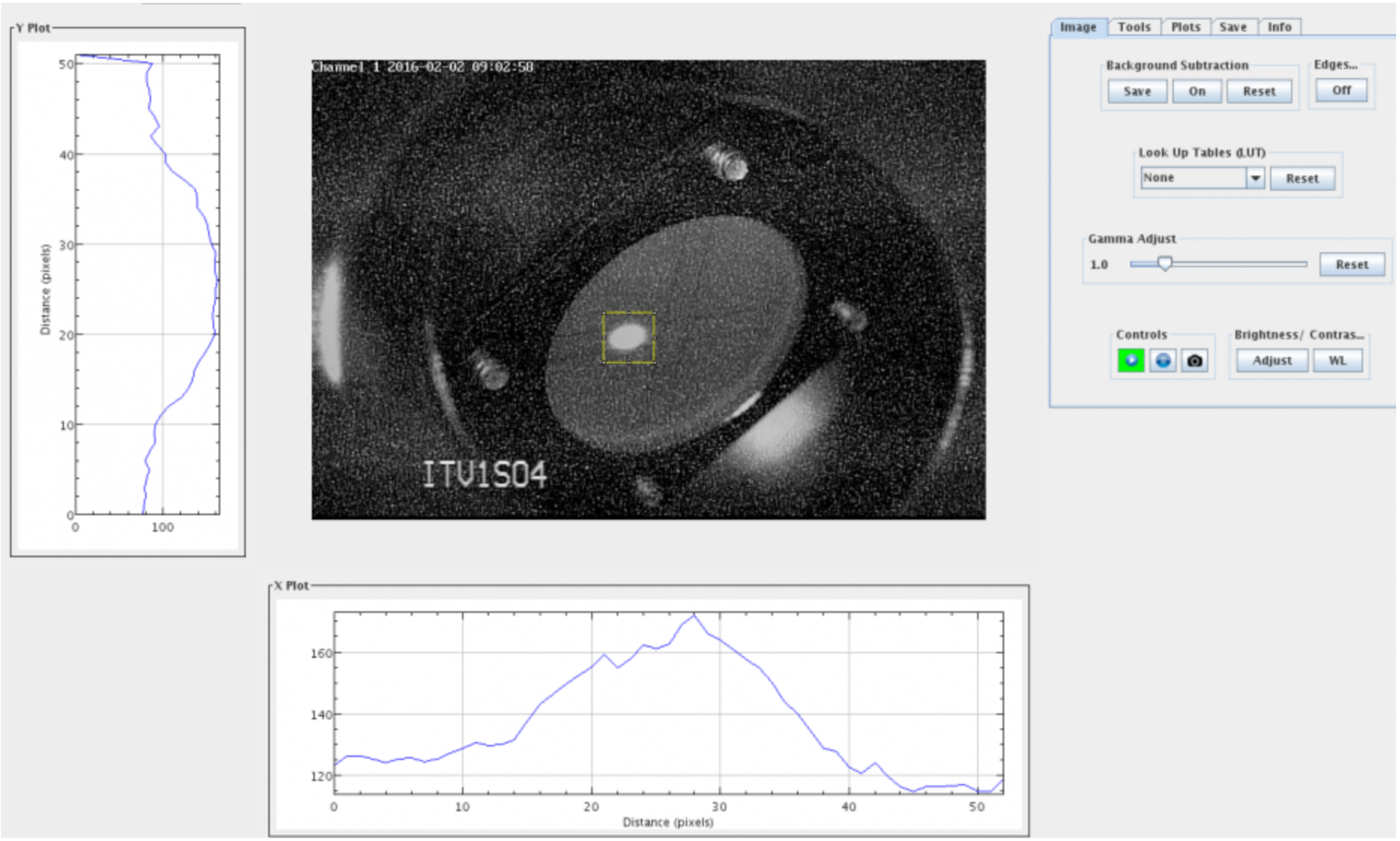
A. Freyberger

Hall D: 5.5-pass Halo (10.5 GeV)



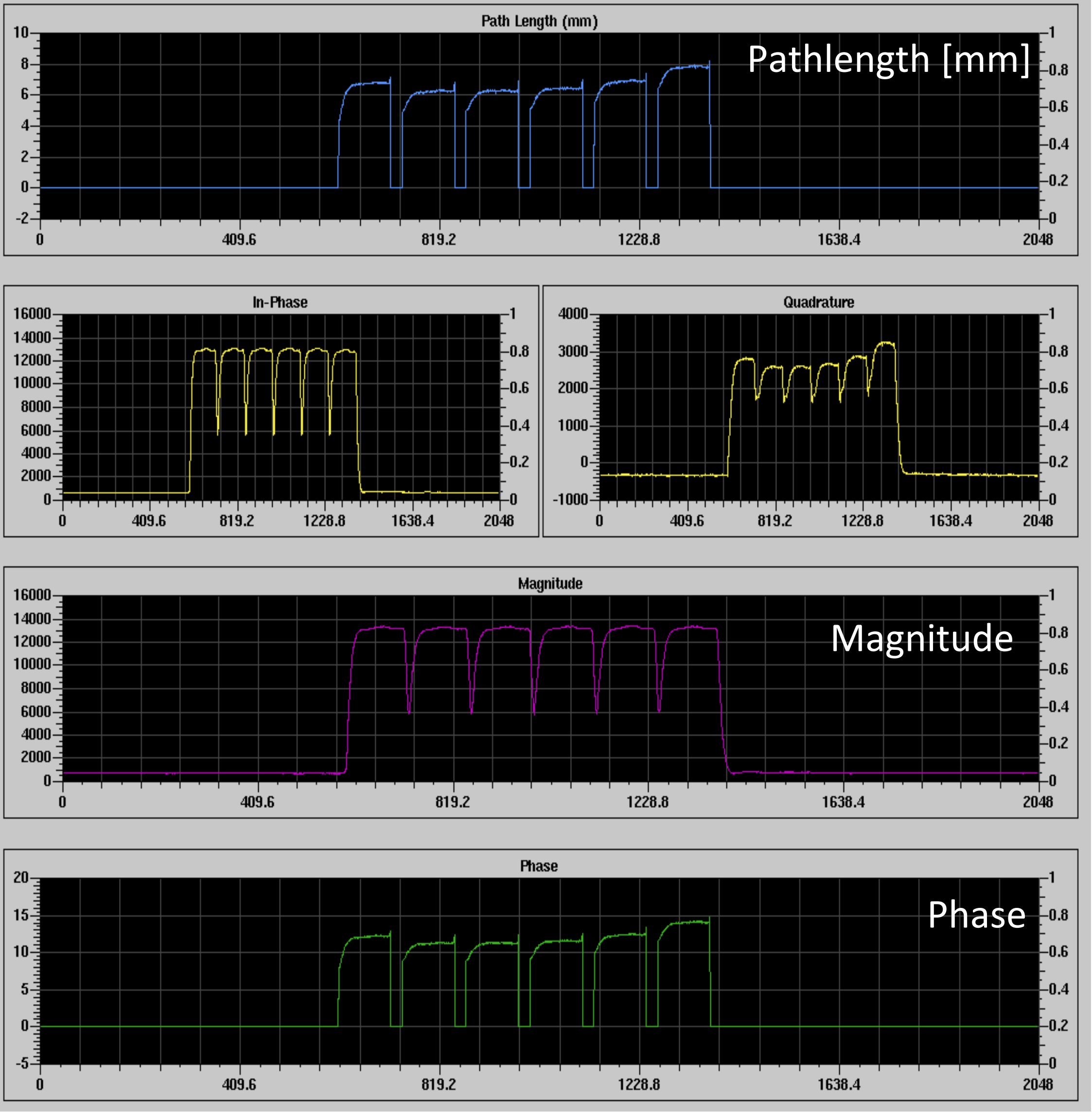
A. Freyberger

Viewer/SLM Profile Diagnostics



- Quantitative tools under development
- SLMs provide real-time parasitic jitter comfort display

New Pathlength Data System



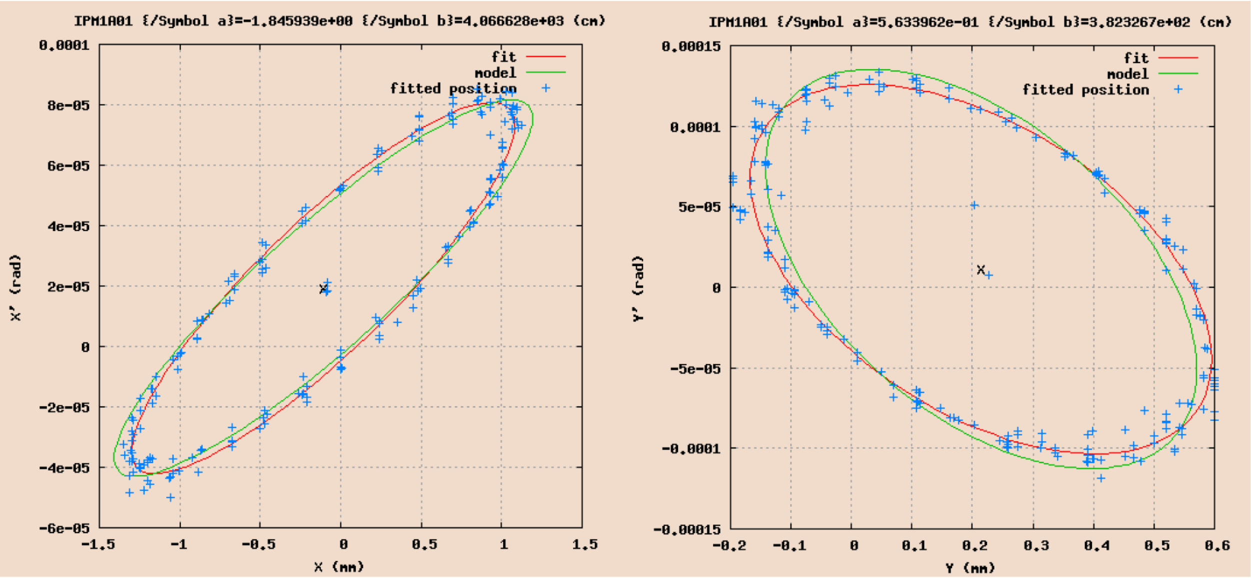
- Longitudinal 1497 MHz cavities, each linac exit (time of arrival monitor)

- Resolution ~50 um
- Calibrated this run
- EPICS connected to archiver for long-term pathlength studies
- Internal current normalization enables laser-to-laser comparison
- Differential time of flight, precise time-of-flight cavity gradient checks

- Master Oscillator Modulation (MOMod) recommissioning and RF cresting development upcoming

Future: RayTrace

- RayTrace: launch/measure **pseudo-emittance** rays
  - Localize errors more precisely than other ORFP techniques
  - Can provide robust, fast, large-scale **transport** matching
  - Does **not** obviate need for beam/transport match
- In need of substantial tool development
  - Similar to successful evolution of quad scan emittance/ matching



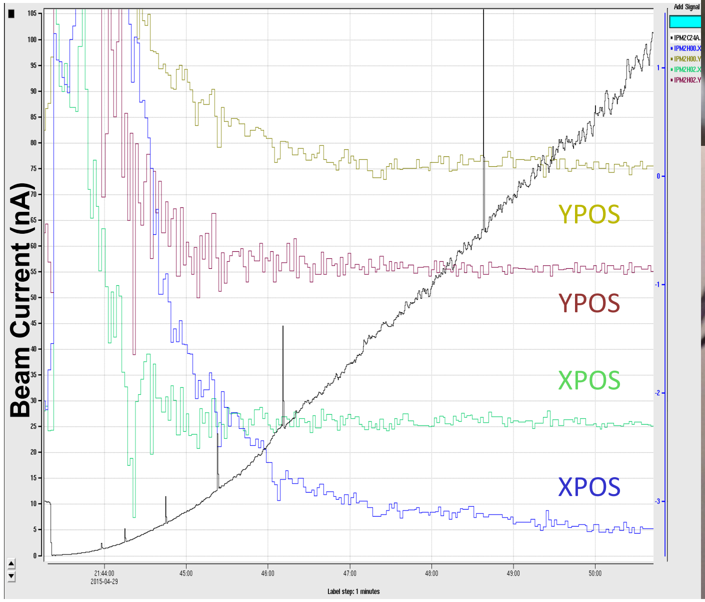
R. Bodenstein
Ph.D. Thesis
Fig. 4.3

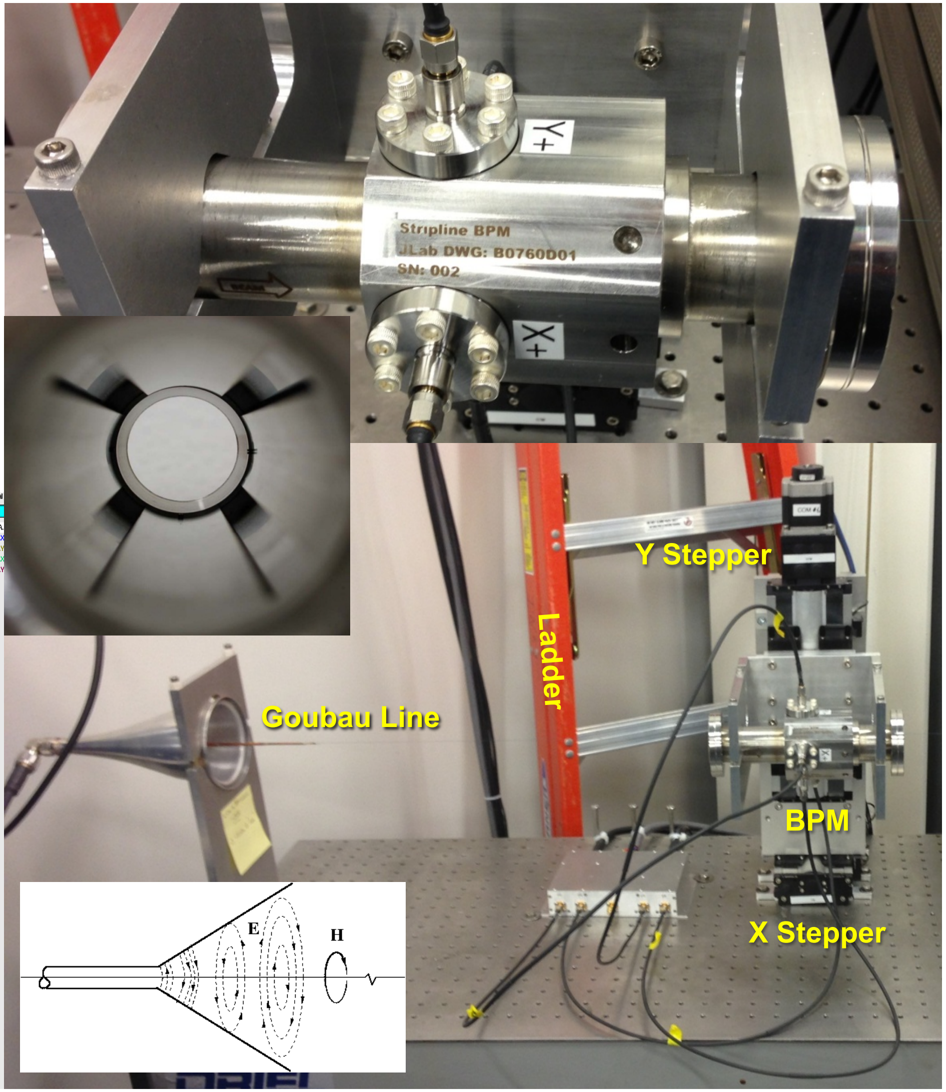
Diagnostic Developments

- Fast FeedBack for Hall D with Digital Receiver BPMs
  - Stripline pickups for higher sensitivity
  - Cavity pickups for very low currents
  - Adaptable to 3 GHz pickup to avoid 1497 pollution?
  - Low current implementation (useful for Hall B?)
- Additional synchrotron radiation imaging stations
- Improving systems for image analysis and use
  - providing flexible controls for image aquisition

Stripline BPMs

- Position calculated as difference-over-sum
- 100um resolution
  120Hz bandwidth
  330 nA of beam

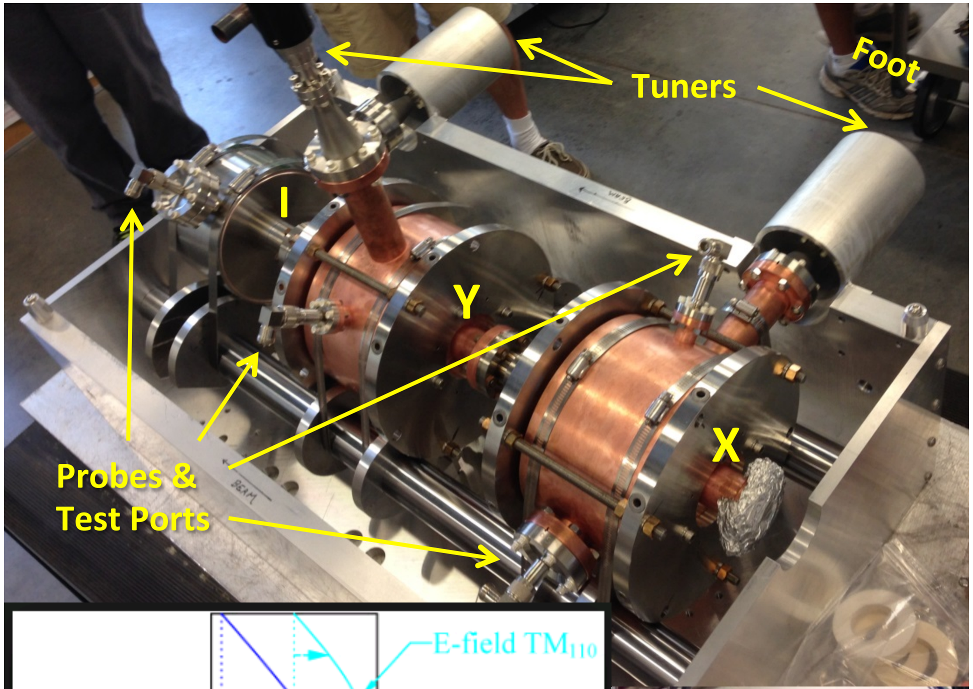


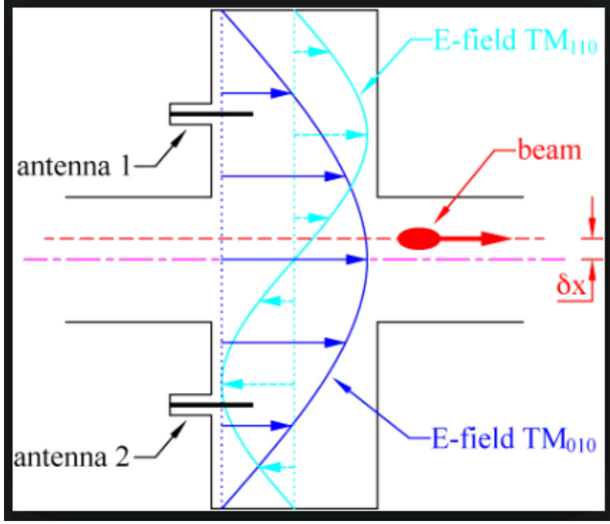


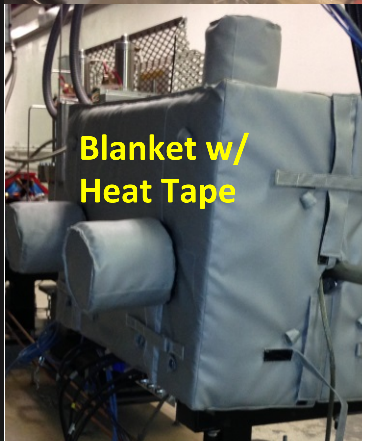
26 Striplines
IPMBS00
IPMBS01
IPMBS02
IPMBS03
IPMBS04
IPMBE01
IPMBE02
IPMBE03
IPMBE04
IPMBT01
IPMBT02
IPMBT03
IPM5C00
IPM5C01
IPM5C02
IPM5C03
IPM5C04
IPM5C05
IPM5C06
IPM5C07
IPM5C08
IPM5C09
IPM5C10
IPM5C11
IPM5C11B
IPMAD00C

Cavity BPMs

- IPM5C11A at shield wall, IPMAD00 at Goniometer
- Positions calculated as X/I & Y/I
  - Signal disappear at boresight
  - X&Y phase shift 180º at zero crossing
  - Phase indicates positive or negative position
- 100um resolution   120Hz bandwidth   1nA of beam
- Beam time needed for commissioning and response characterization

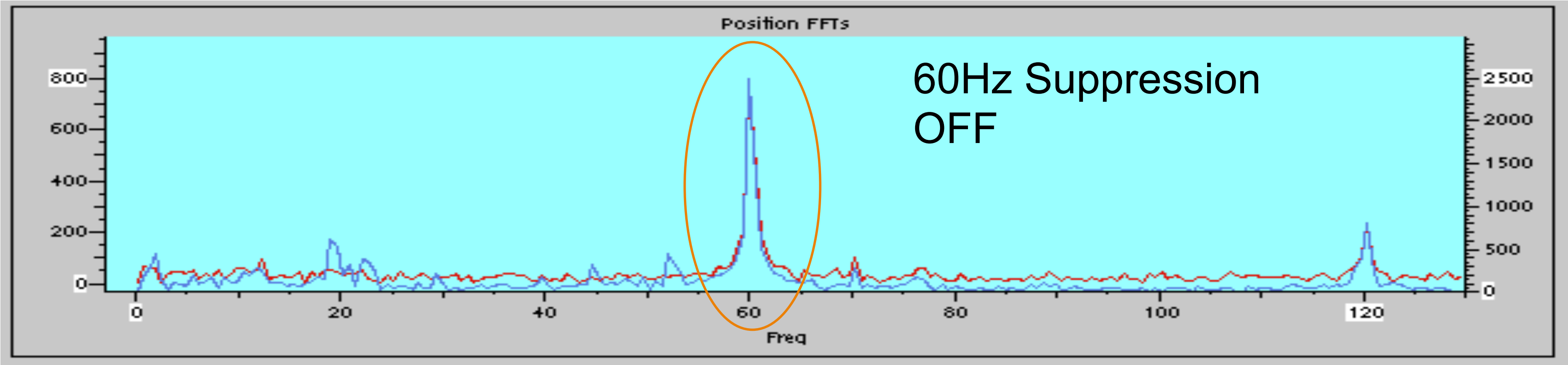




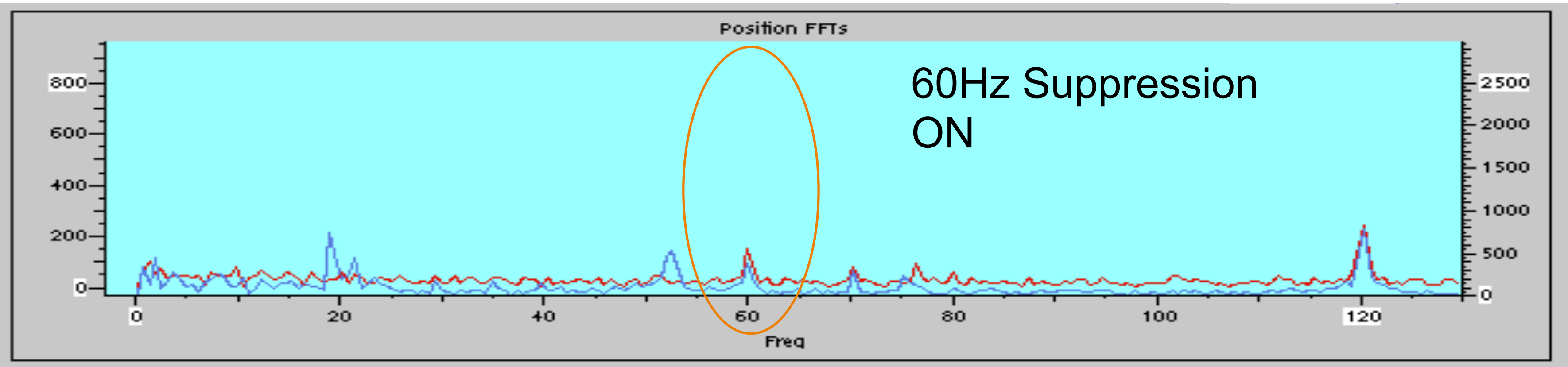


HW Testing: 60Hz Suppression

- Line-synchronized Feedforward suppression
- Proved hardware capable of canceling motion



IPM5C07 Stripline Frequency Response



Accelerator Physics Summary

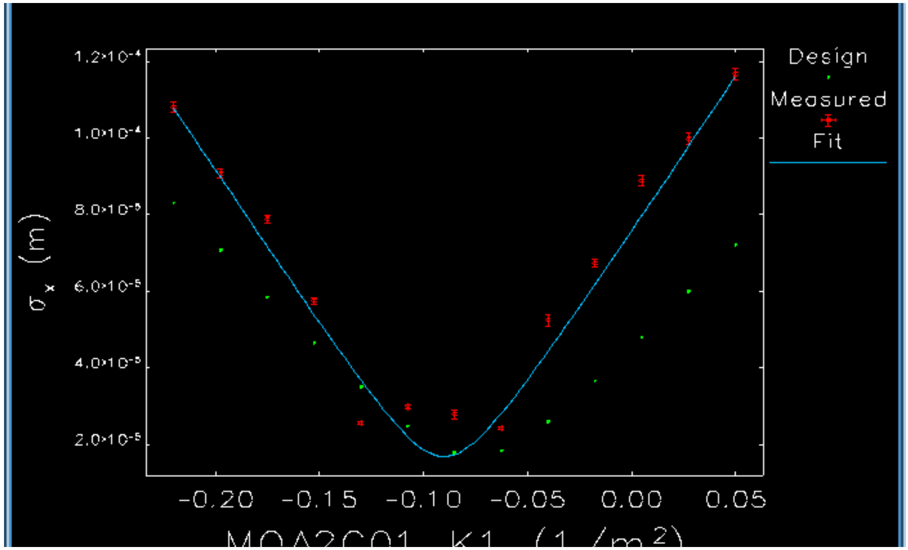
- CASA continuously supports 12 GeV CEBAF operations
  - Optics and analysis support, beam studies program
- 12 GeV CEBAF program meets beam requirements
  - Systematic transverse match, emittance, bunch length measurements
  - Synchrotron-radiation emittance growth understood
- 12 GeV diagnostics being re-commissioned, newly commissioned, and in continuing development
  - SLMs, stripline BPMs are operational successes
  - Working towards 6D tomography, rayTrace global match

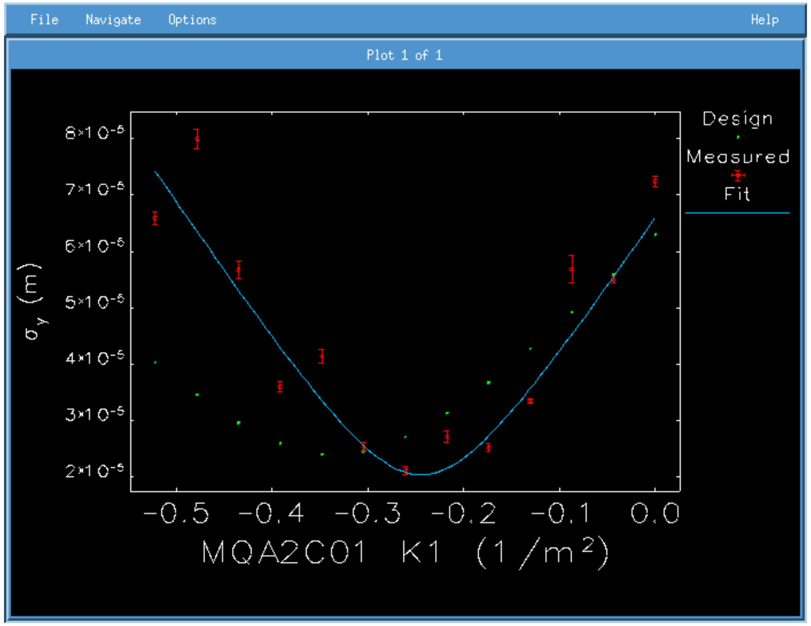
Accelerator Status

- Meeting requirements
- Developing plans to handle emerging issues
  - Vibration sensitivity
  - More rapid recovery to gradient for C100s
- Developing procedures to use new capabilities
  - Improved beam timing diagnostics
  - FFB expansion to HallD
  - Additional features of new BPMs

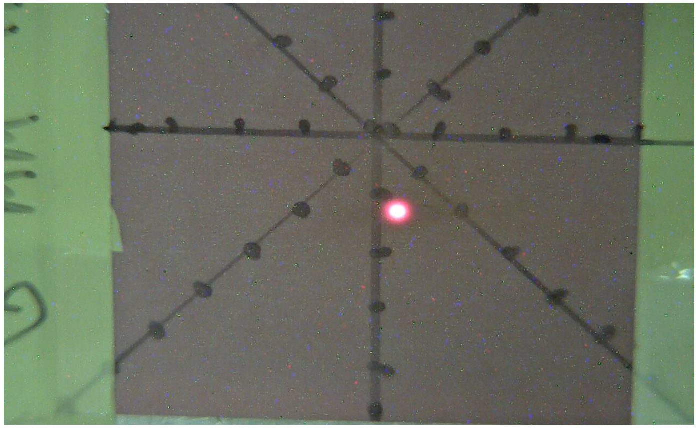
- The land of opportunity

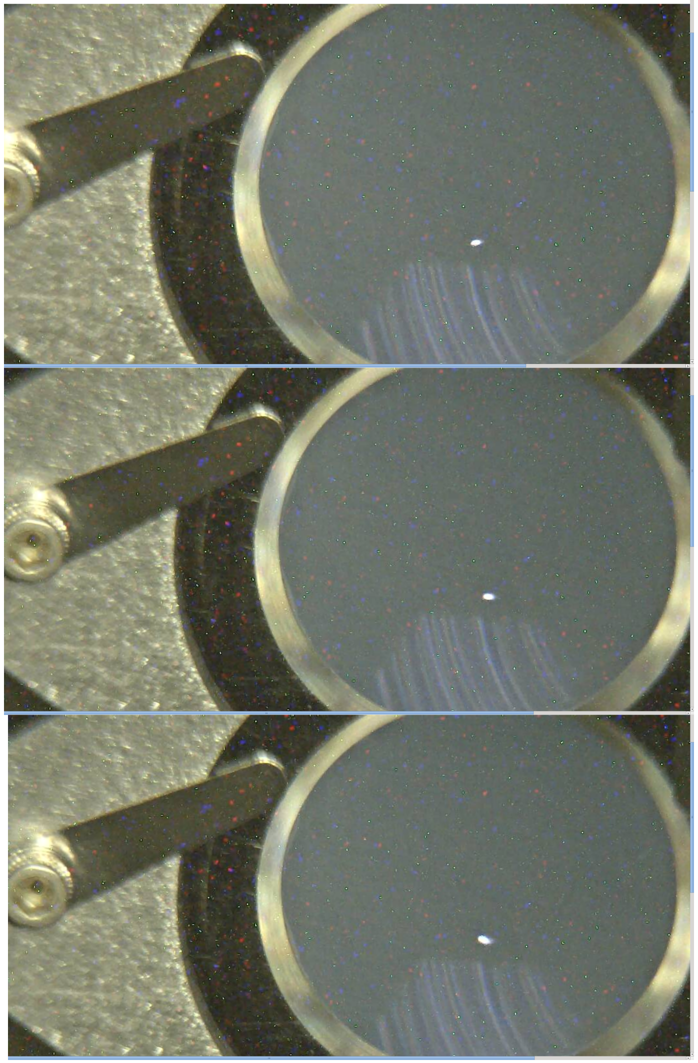
Incoming Beam Characterization (2C04)





Faraday Cup Viewer (Chromox/YAG/OTR)





Target Plane Harp (HPS)