LERF

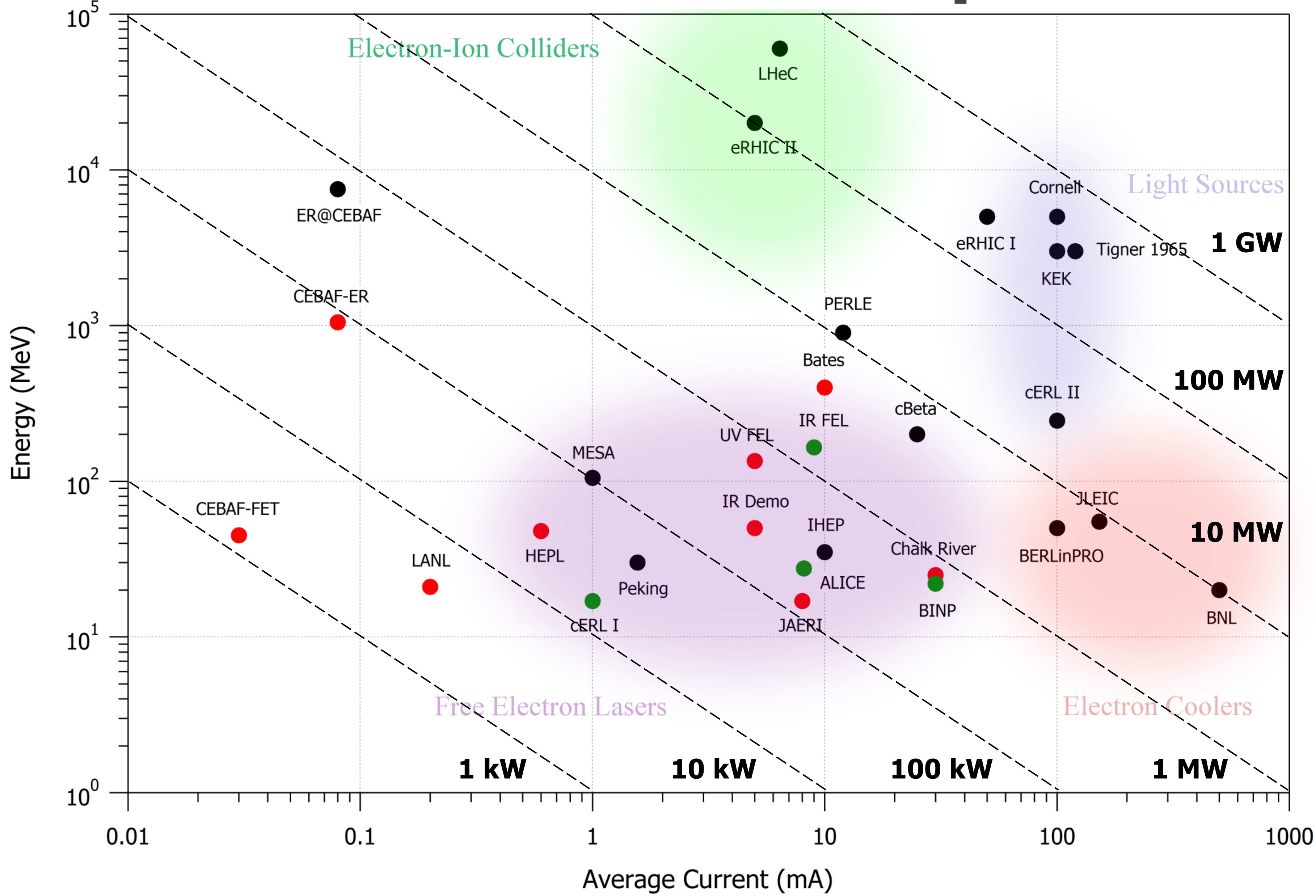
New Life for the FEL

Chris Tennant

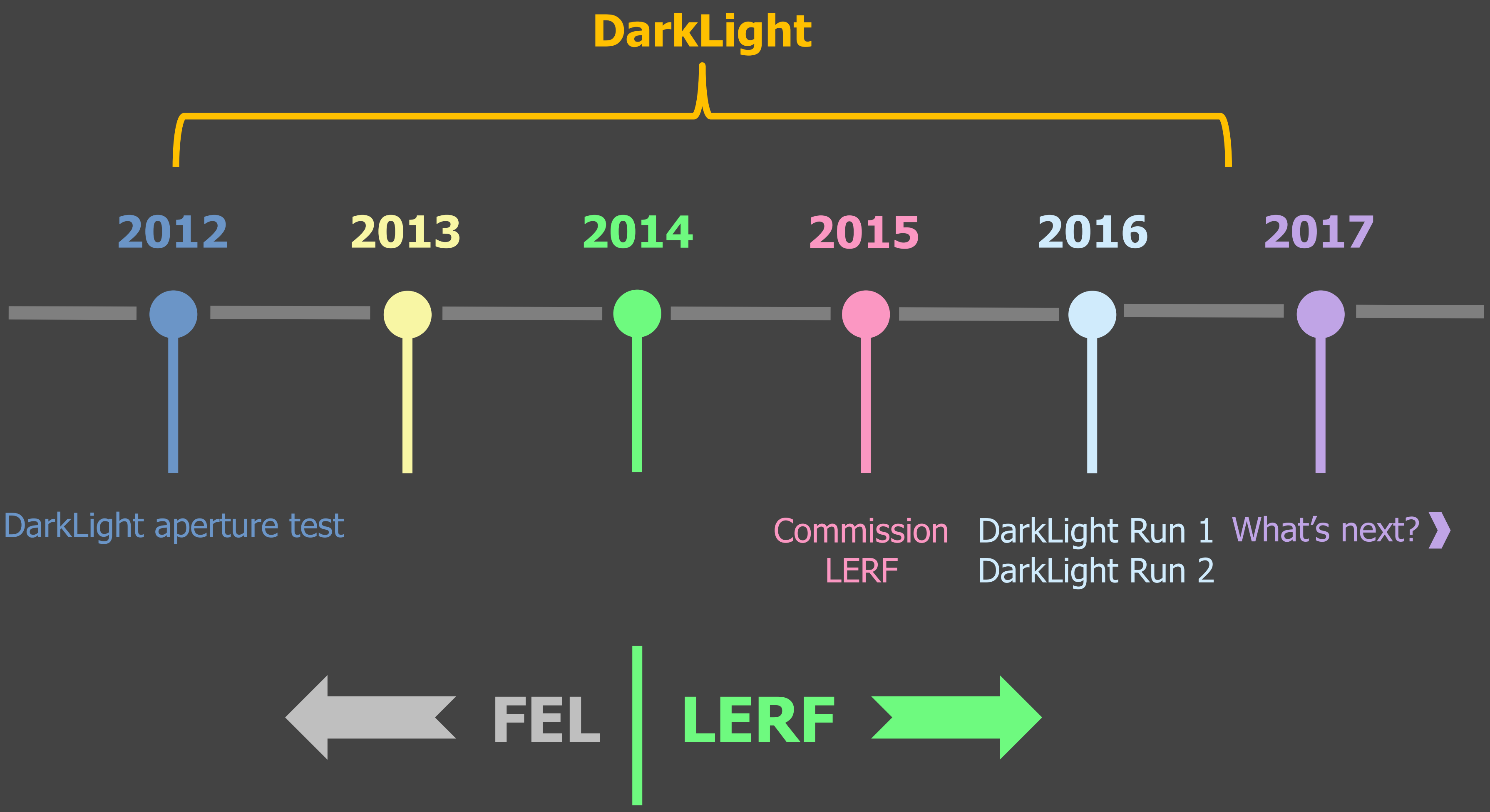
Jefferson Laboratory

7th International ERL Workshop | June 18-23, 2017

Global ERL Landscape

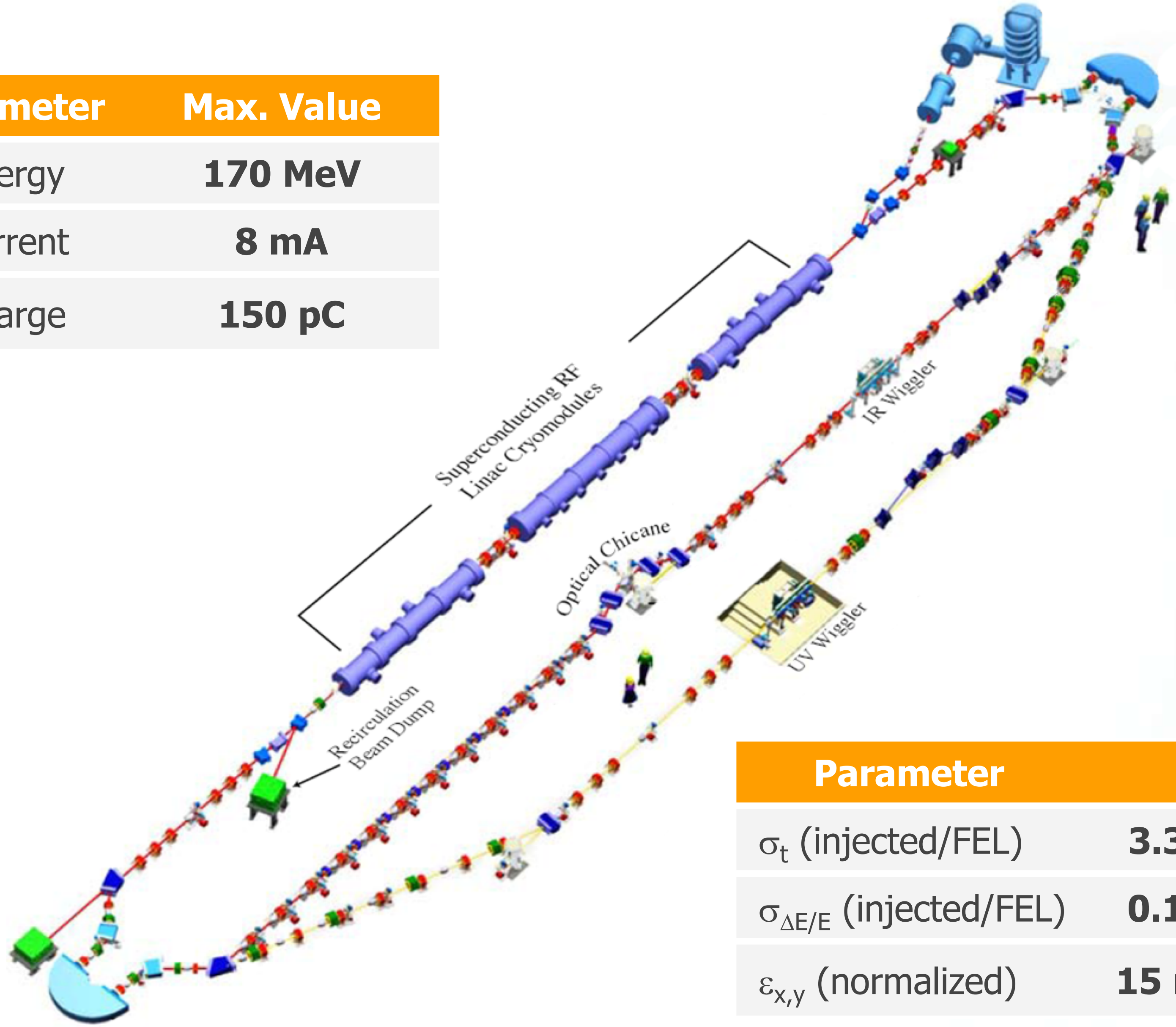


Outline


DarkLight
2012
2013
2014
2015
2016
2017
DarkLight aperture test
Commission LERF
DarkLight Run 1
DarkLight Run 2
What's next?
FEL
LERF

Jefferson Lab ERL Driver

Parameter	Max. Value
Energy	**170 MeV**
Current	**8 mA**
Charge	**150 pC**



Parameter	RMS
σ_t (injected/FEL)	**3.3/0.12 ps**
$\sigma_{\Delta E/E}$ (injected/FEL)	**0.15/0.5 %**
$\varepsilon_{x,y}$ (normalized)	**15 mm-mrad**

The DarkLight Experiment

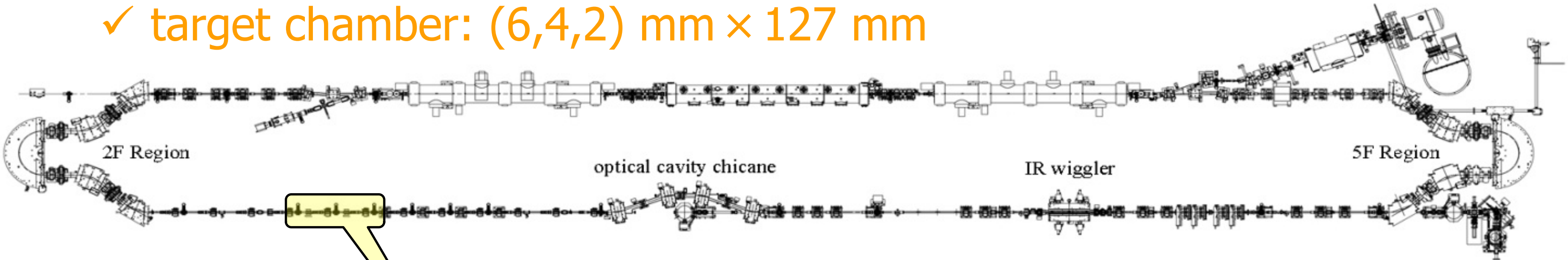
- search for a dark matter particle by studying e^- p scattering in an internal target
- choice of machine configuration is driven by the requirement to:
  1. minimize background radiation
     - ✓ reduce cavity gradients to run 100 MeV (from 130 MeV) → avoid onset of field emission
  2. minimize beam losses
     - ✓ reduce bunch charge from 135 pC to 60 pC → reduce transverse and longitudinal emittance, reduce halo
     - ✓ low momentum spread bunch → reduce impact of dispersion errors, mitigate resistive wall heating by keeping bunch long (3.3 ps rms vs 0.12 ps rms)

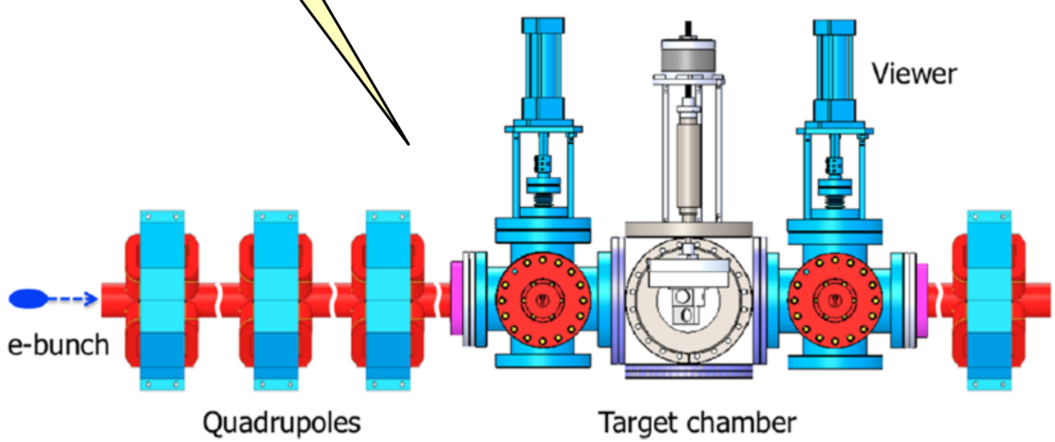
DarkLight: Aperture Test (2012)

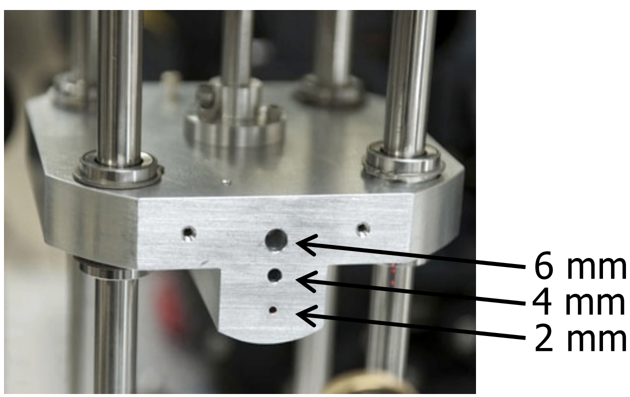
- goals:
  - ✓ maximize target gas density
  - ✓ minimize tube diameter
  - ✓ minimize beam background

how small can you go?

- install a test aperture in the beamline, configure the machine for DarkLight experimental conditions and quantify beam loss
  - ✓ target chamber: (6,4,2) mm × 127 mm

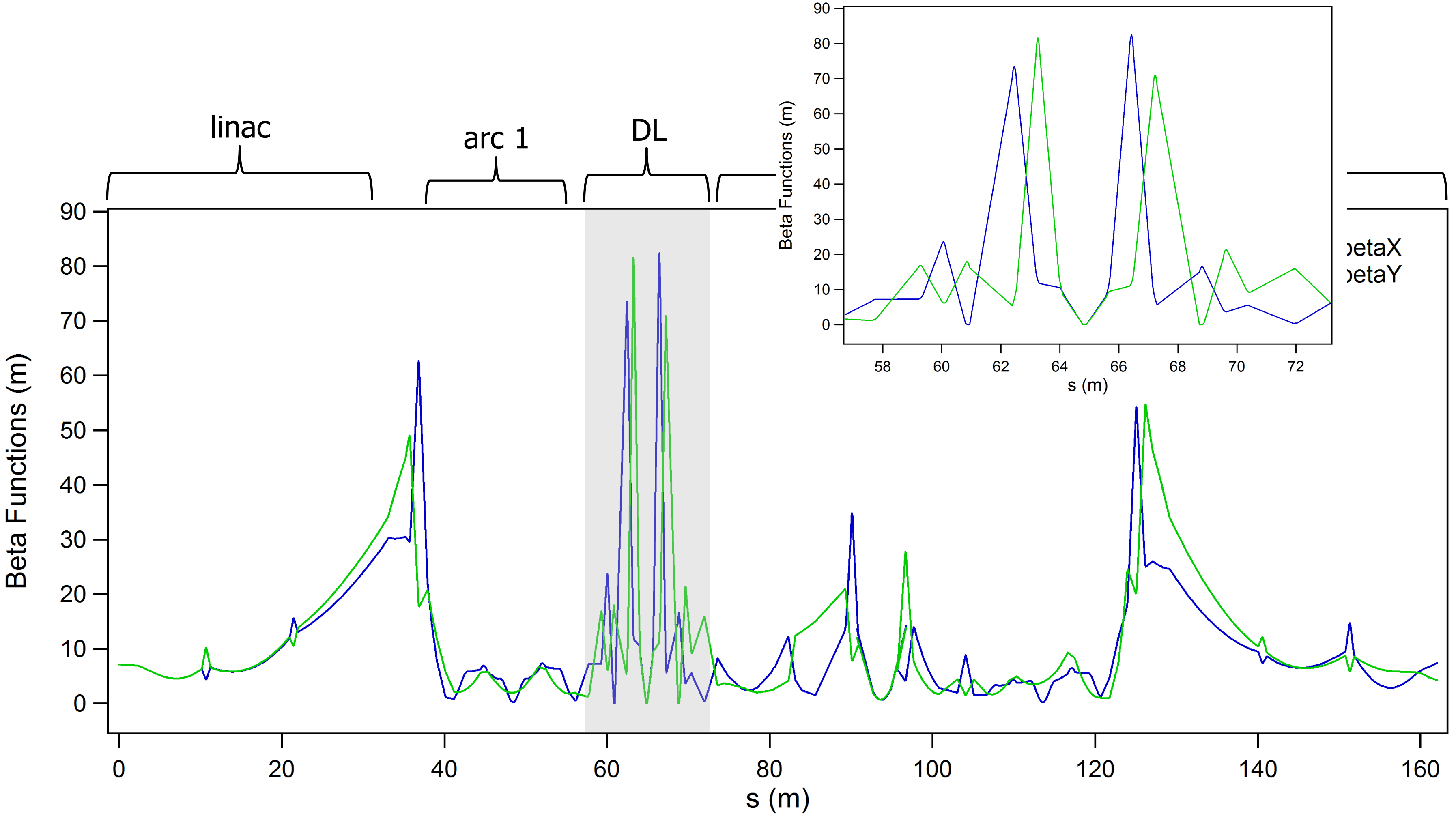






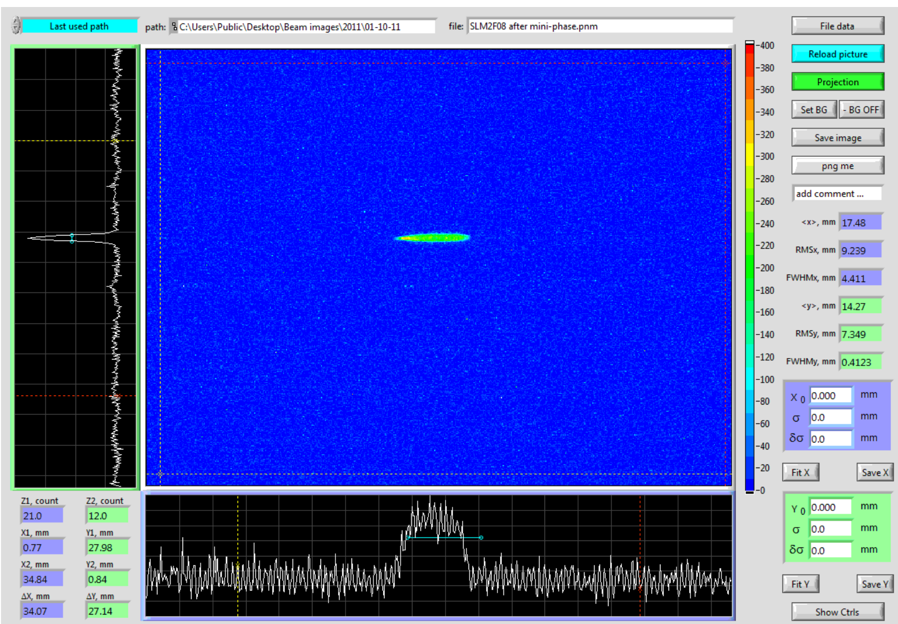
Optics Configuration

- install test aperture(s) in well-characterized region with a lot of diagnostics
  - ✓ phase-space exchange unavailable

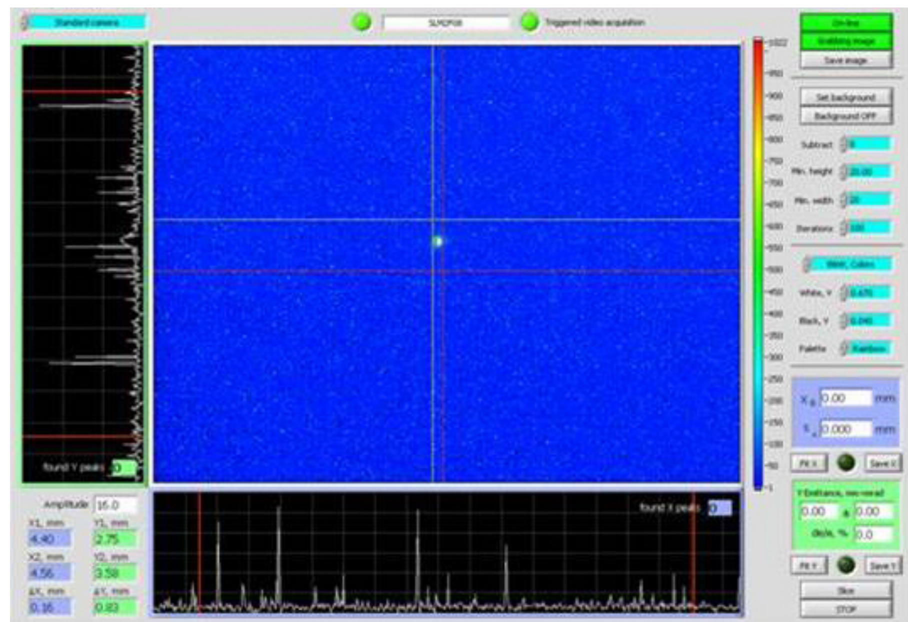


Longitudinal Match

- ERL performance sensitive to longitudinal dynamics
  - ✓ **FEL**: short, moderate momentum spread bunch at wiggler
  - ✓ **DarkLight**: long, low momentum spread bunch at target
- cross-phasing of linac modules provides a single phase setpoint to go from short bunch to small momentum spread operation
- maintain phasing and setup procedures from FEL configuration



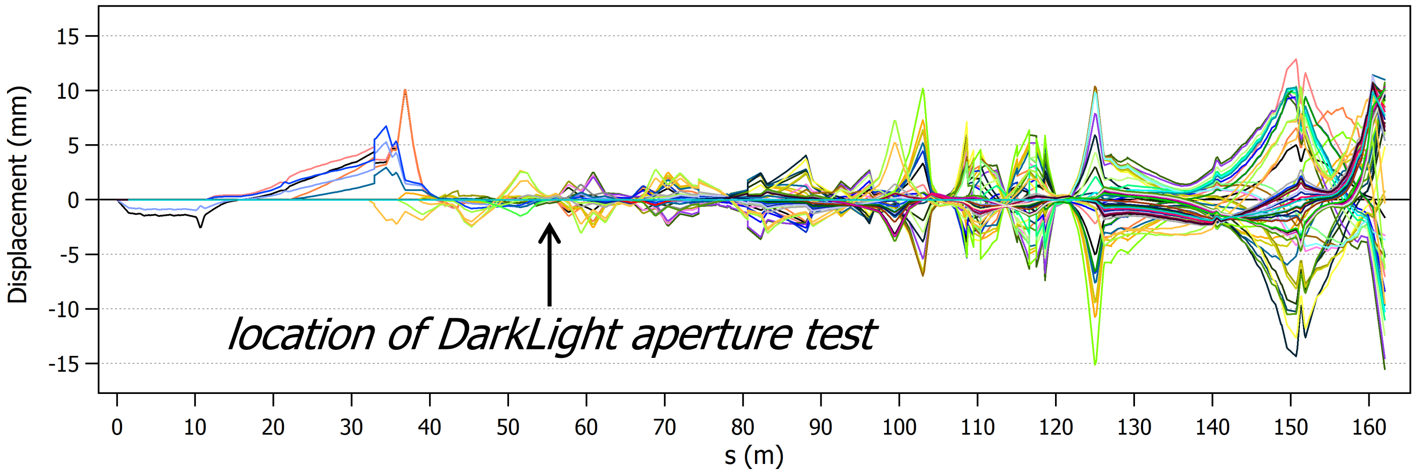
RMS energy spread: 0.5%



RMS energy spread < 0.01%

Halo Management

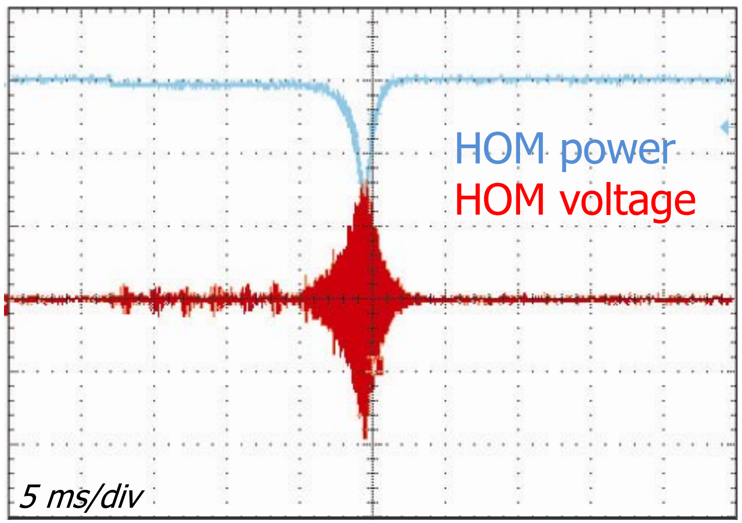
- **halo** ≡ large emittance, low intensity component(s) of beam
  - ✓ mismatched to core
  - ✓ sample large amplitudes
  - ✓ can be tightly focused (but with large divergence)
  - ✓ "stuff" that's too dim to see with standard diagnostics
- map out large amplitude response of lattice ("halo map")



- use mismatch to adjust halo envelopes at aperture constraints
  - ✓ find quad where halo large, core beam small
  - ✓ adjust "halo" knob, reduce halo size at aperture
  - ✓ use BLMs as diagnostic

Multipass Beam Breakup (2005)

- BBU first observed in IR FEL Driver in 2005
  - ✓ full suite of measurements used to characterize the instability
  - ✓ suppression techniques employed successfully

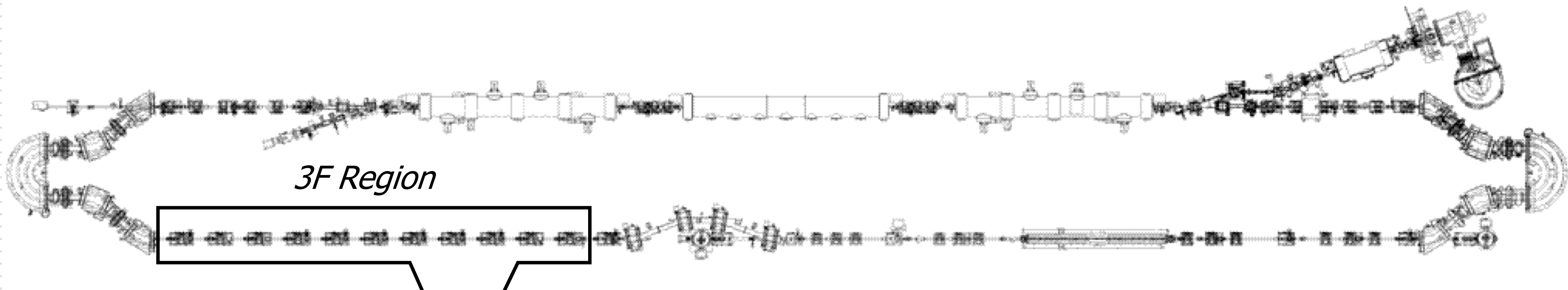


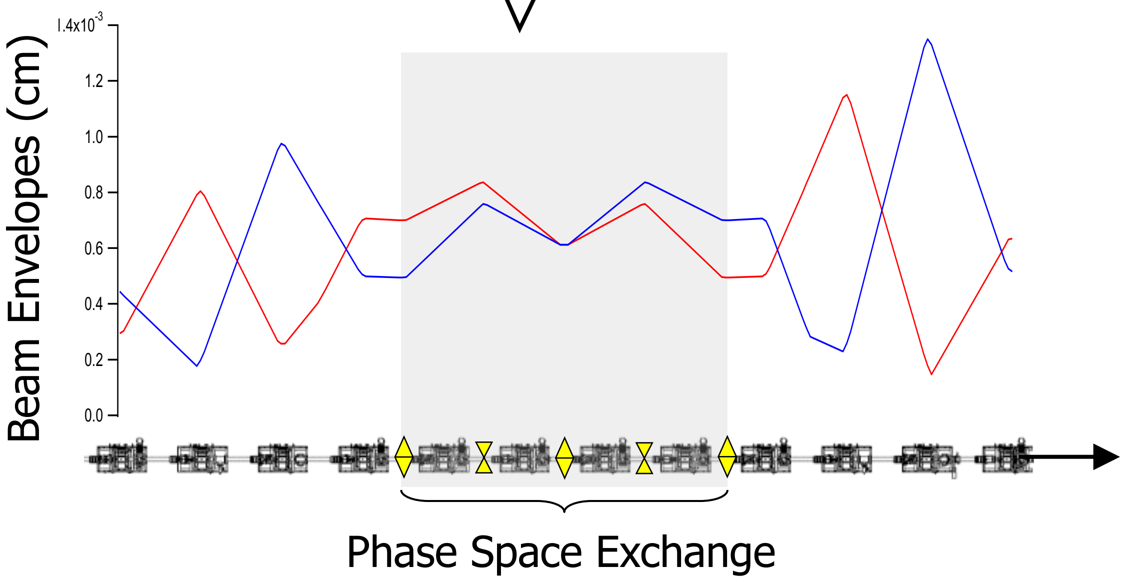
- simulate BBU with several codes
- experimentally measure threshold current using variety of techniques

	Method	$I_{threshold}$ (mA)
Simulation	**MATBBU** *(Yunn, Beard)*	2.1
	TDBBU *(Krafft, Beard)*	2.1
	GBBU *(Pozdeyev)*	2.1
	BI *(Bazarov)*	2.1
Experimental	Direct Observation	2.3 ± 0.2
	Growth Rates	2.3 ± 0.2
	Kicker-based BTF	2.3 ± 0.1
	Cavity-based BTF	2.4 ± 0.1
Analytic	Analytic Formula	2.1

Phase Space Exchange

5 skew quadrupoles are installed in the backleg to exchange the horizontal and vertical phase spaces

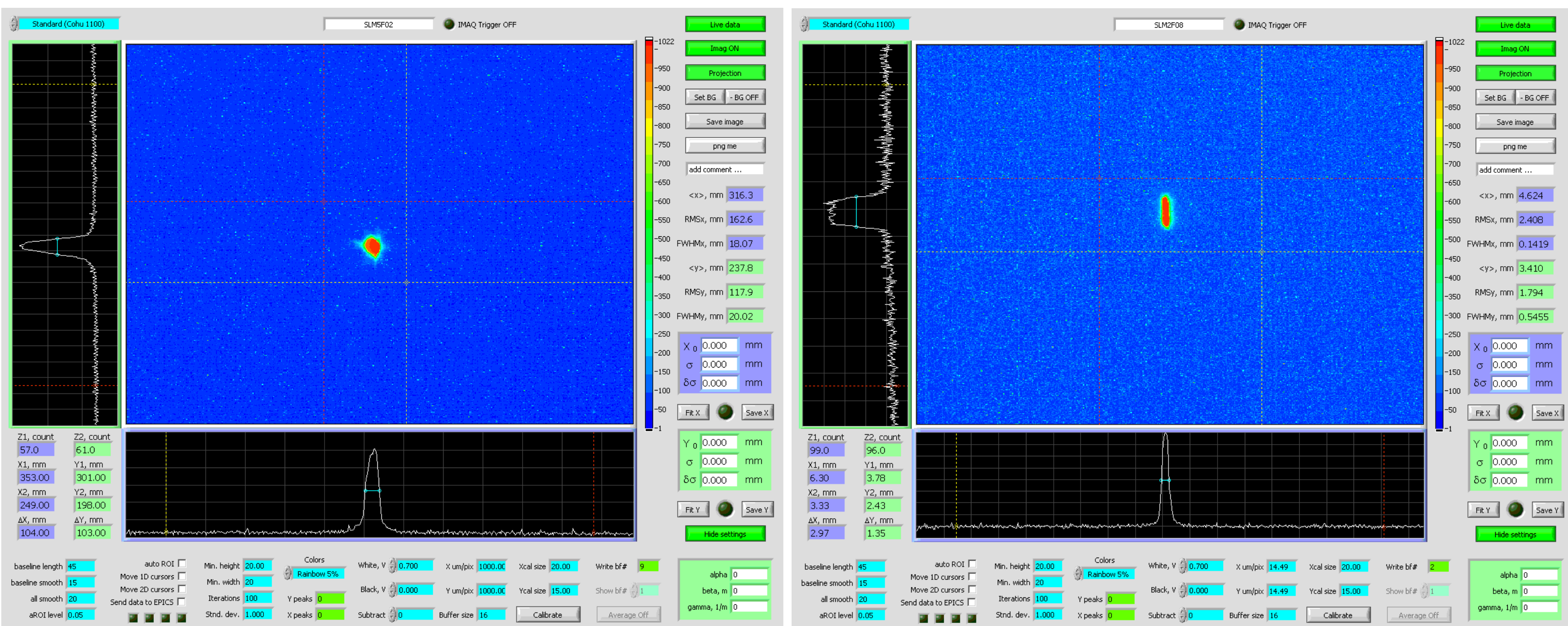




converts a BBU-induced vertical *(horizontal)* kick on the first pass to a horizontal *(vertical)* displacement on the second pass

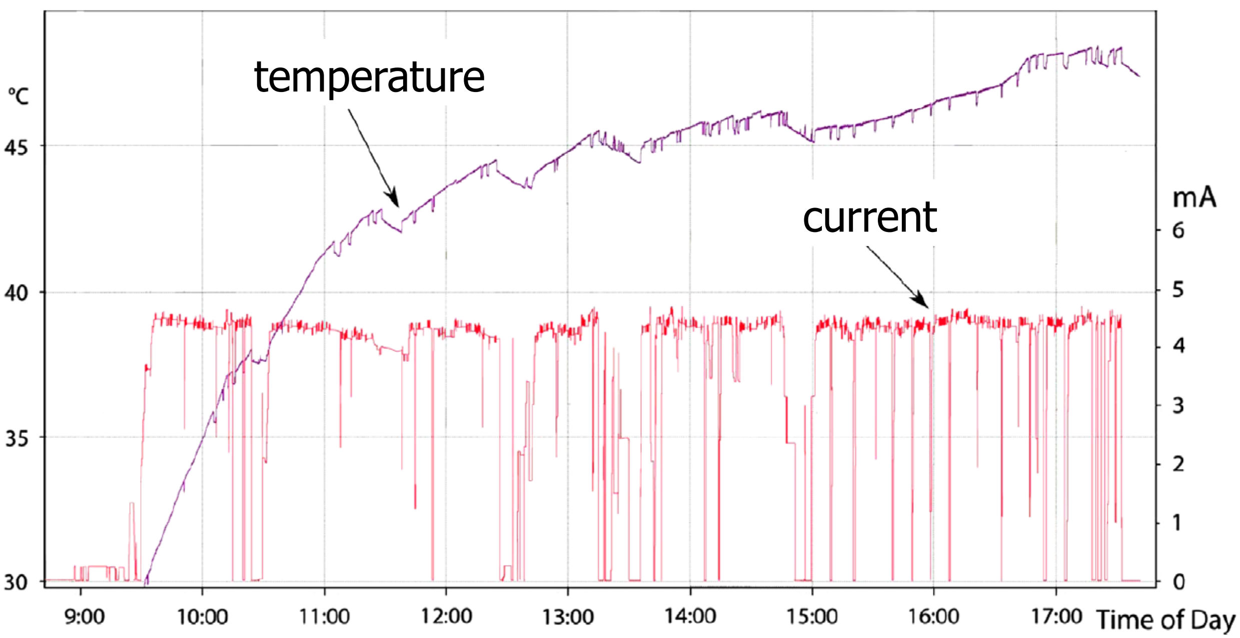
Multipass Beam Breakup (2012)

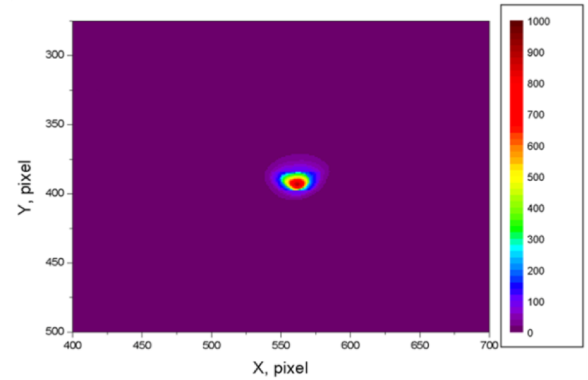
- NO phase space exchange + high current = BBU
- energy fluctuations + chromaticity → modifies phase advance → changes recirculation matrix → BBU
- control onset by adjusting the energy of a vernier cavity (10s to 100s of keV)
  - ✓ "cat's eye" image on SLM indicates imminent BBU-induced trip

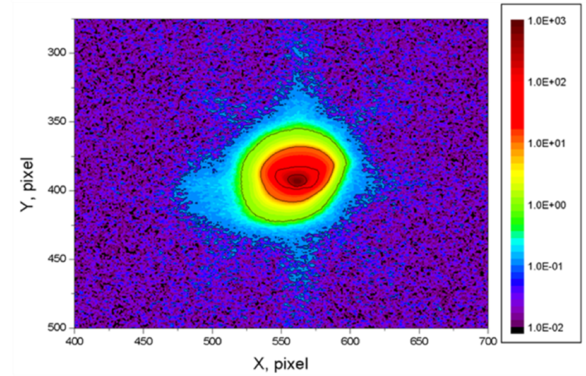


Results

- multiple runs of varying length
- final run delivered 0.43 MW of beam (4.3 mA at 100 MeV/c) for nearly 7 hours through the 2 mm aperture with average beam loss of 2.8 ppm





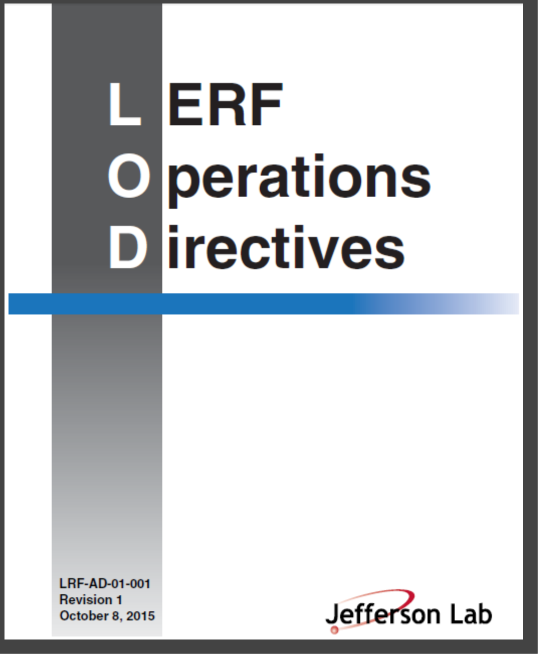


- development of large dynamic range viewer

Transition (2014)

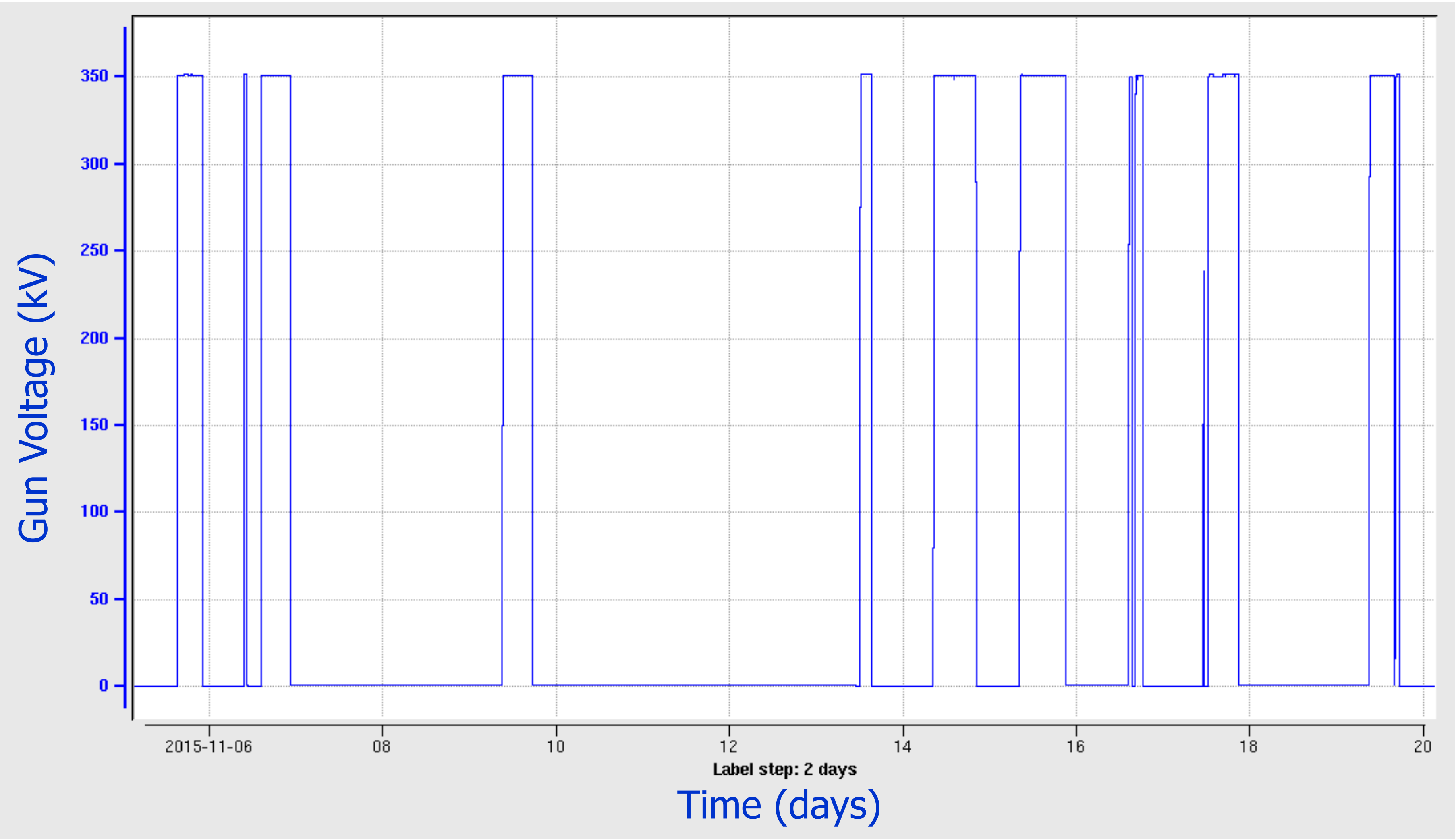
FEL R : Low Energy Recirculator Facility

- FEL group absorbed into the Accelerator Division
- operations group assumes responsibility for “driving” LERF
  - ✓ presents unique challenges for a machine used as a testbed
  - ✓ not a user-facility
  - ✓ proceduralizing 15 years of institutional knowledge is difficult



Commissioning the LERF (2015)

- from machine off for 2 years to CW operation in 70 hours

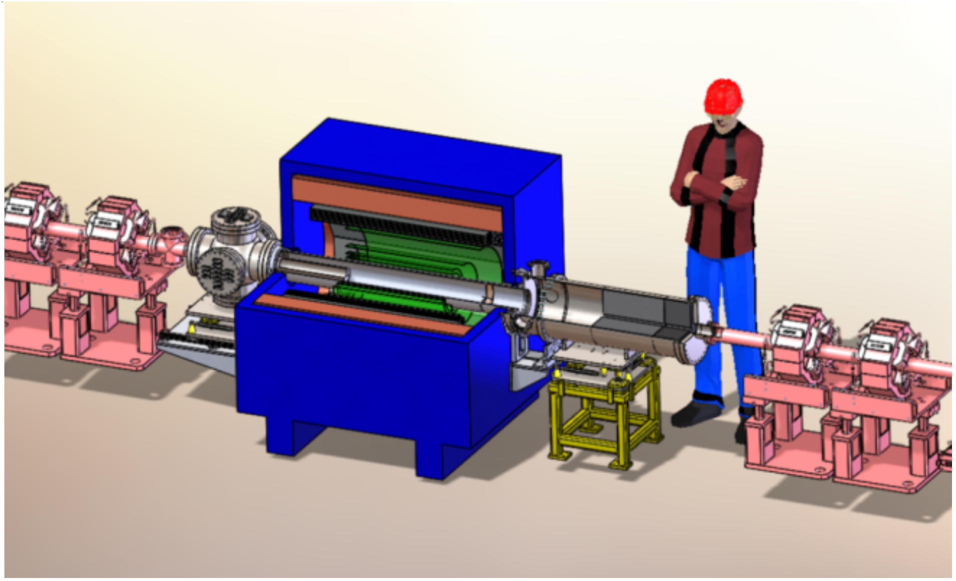


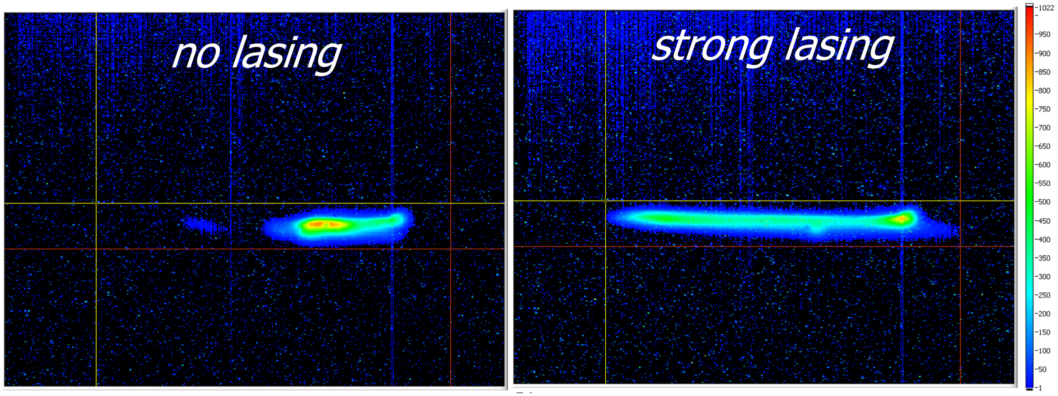
Observing BBU, Again

mechanism: F100 installed in Zone 2 → dangerous HOMs at locations of <u>lower</u> beam energy → lower threshold current

DarkLight Interaction Region Design

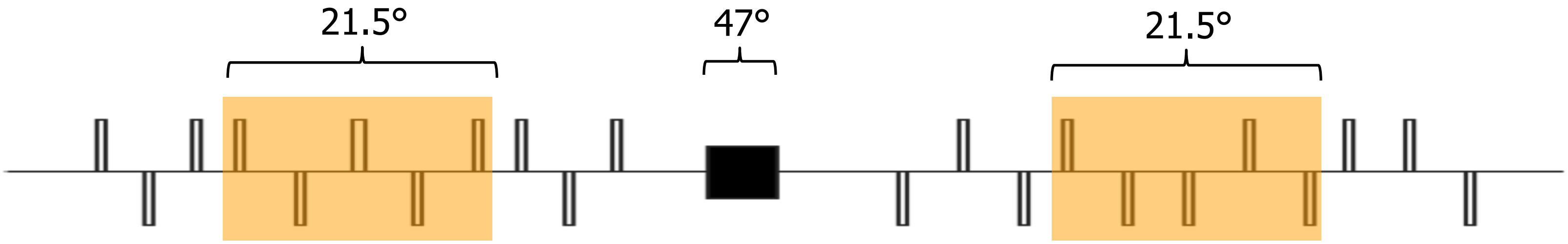
- interaction region consists of:
  - ✓ gaseous hydrogen target
  - ✓ detector
  - ✓ 5 kG solenoid (1.1 m)
  - ✓ Moller dump (0.5 m)
- installed in place of IR wiggler
- effect on the beam
  - ✓ transversely couple the beam
  - ✓ increase transverse spot sizes
  - ✓ increase energy spread

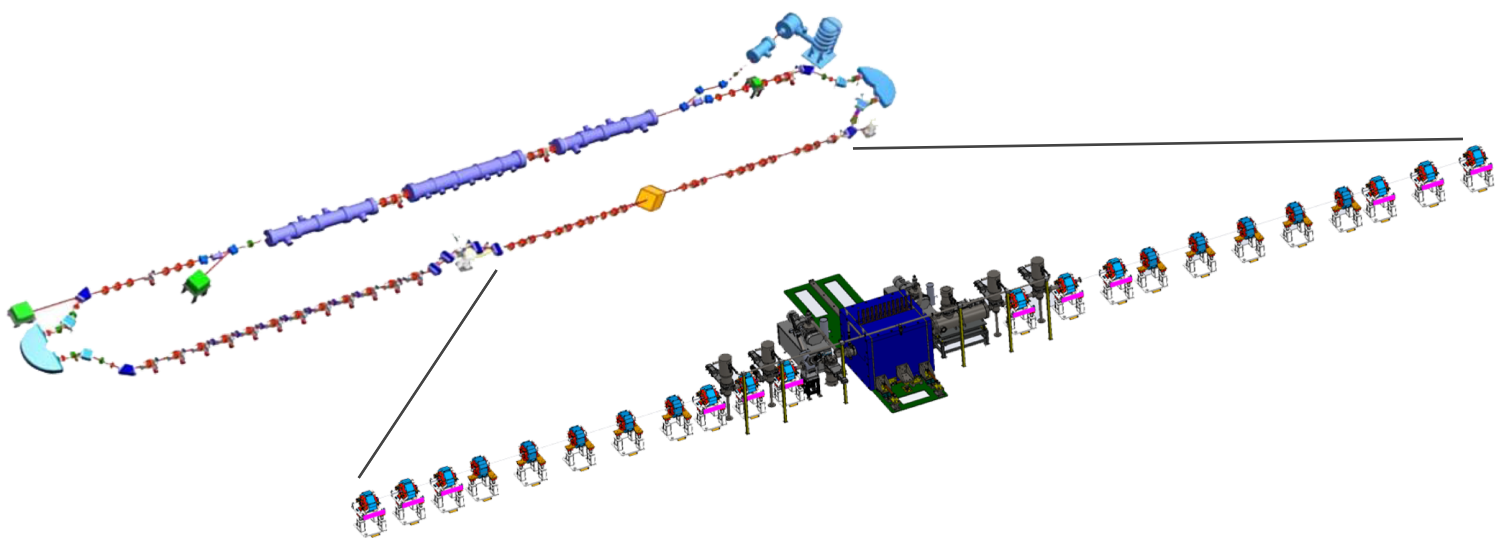




DarkLight Interaction Region Design

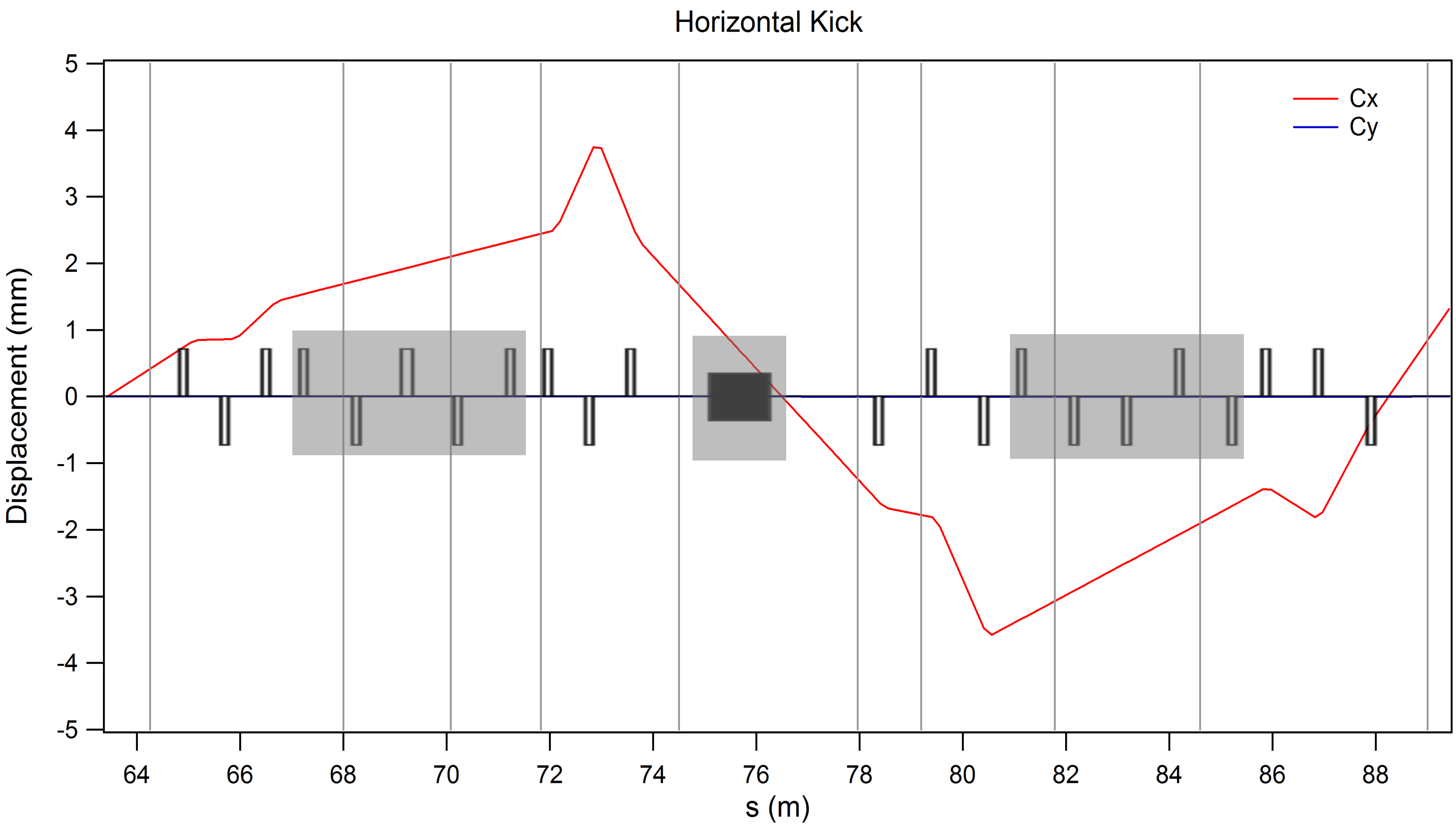
- requirements of design
  - ✓ match (transverse and longitudinally) to the target
  - ✓ linac-to-linac transport must exchange transverse phase spaces
  - ✓ transport degraded, coupled beam to dump
- significant re-work of backleg region between chicane and arc





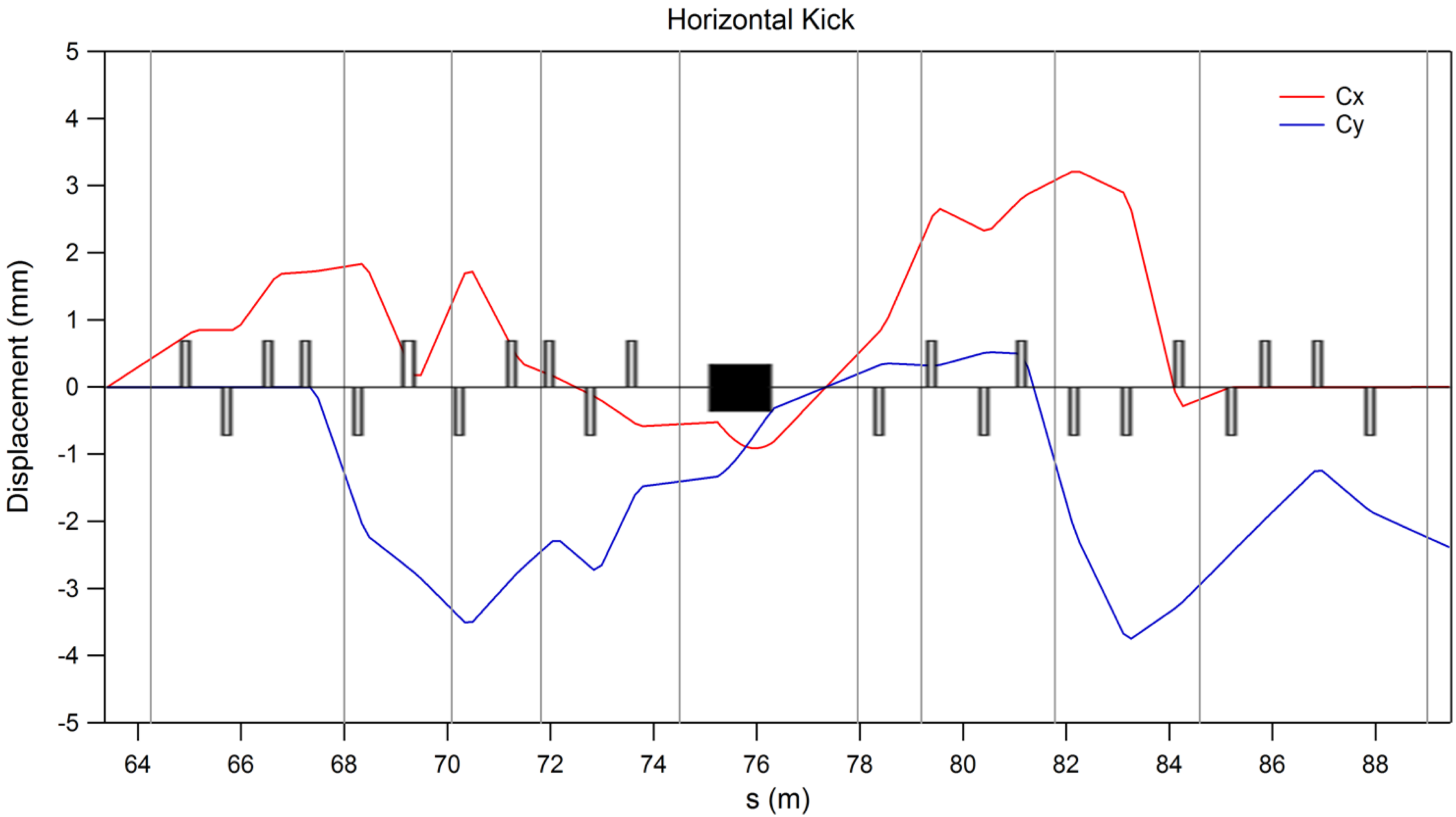
Interaction Region: Orbit Response

- fall 2015 configuration: no skew quadrupoles, no solenoid



Interaction Region: Orbit Response

- fall 2016 configuration: skew quadrupoles and solenoid ON



DarkLight: Engineering Run (2016)

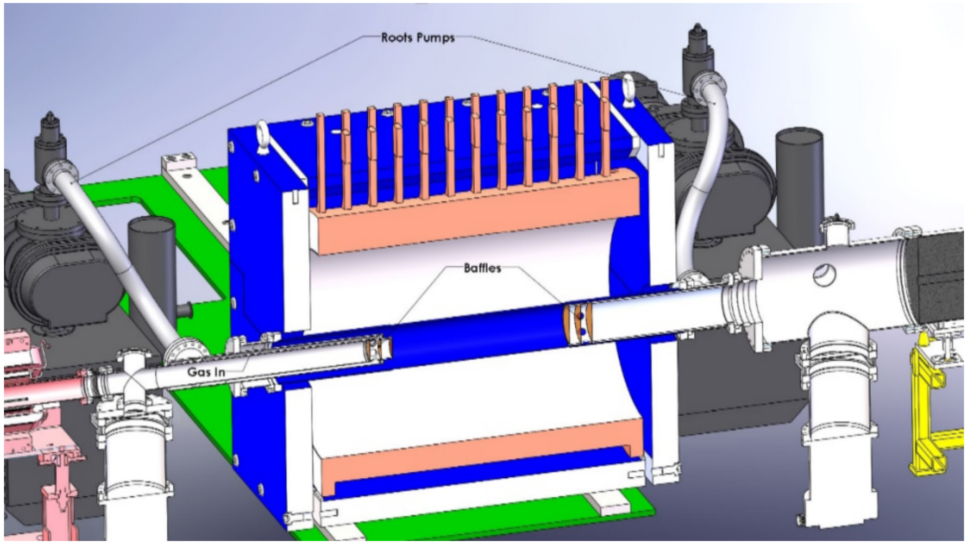
- **Goal: run power with skew quadrupoles and solenoid ON**
- ran 24 hours/day for 8 days
- solenoid installed, but not target
- solenoid vertical steering
- element database growing pains
  - ✓ QTs set wrong → could not resolve remnant dispersion
- diagnostic headaches
  - ✓ BPM + viewer + Happek

could not find a matching solution with skew quadrupoles and solenoid on

- ran 6% duty factor at 1.25 mA with minimal losses

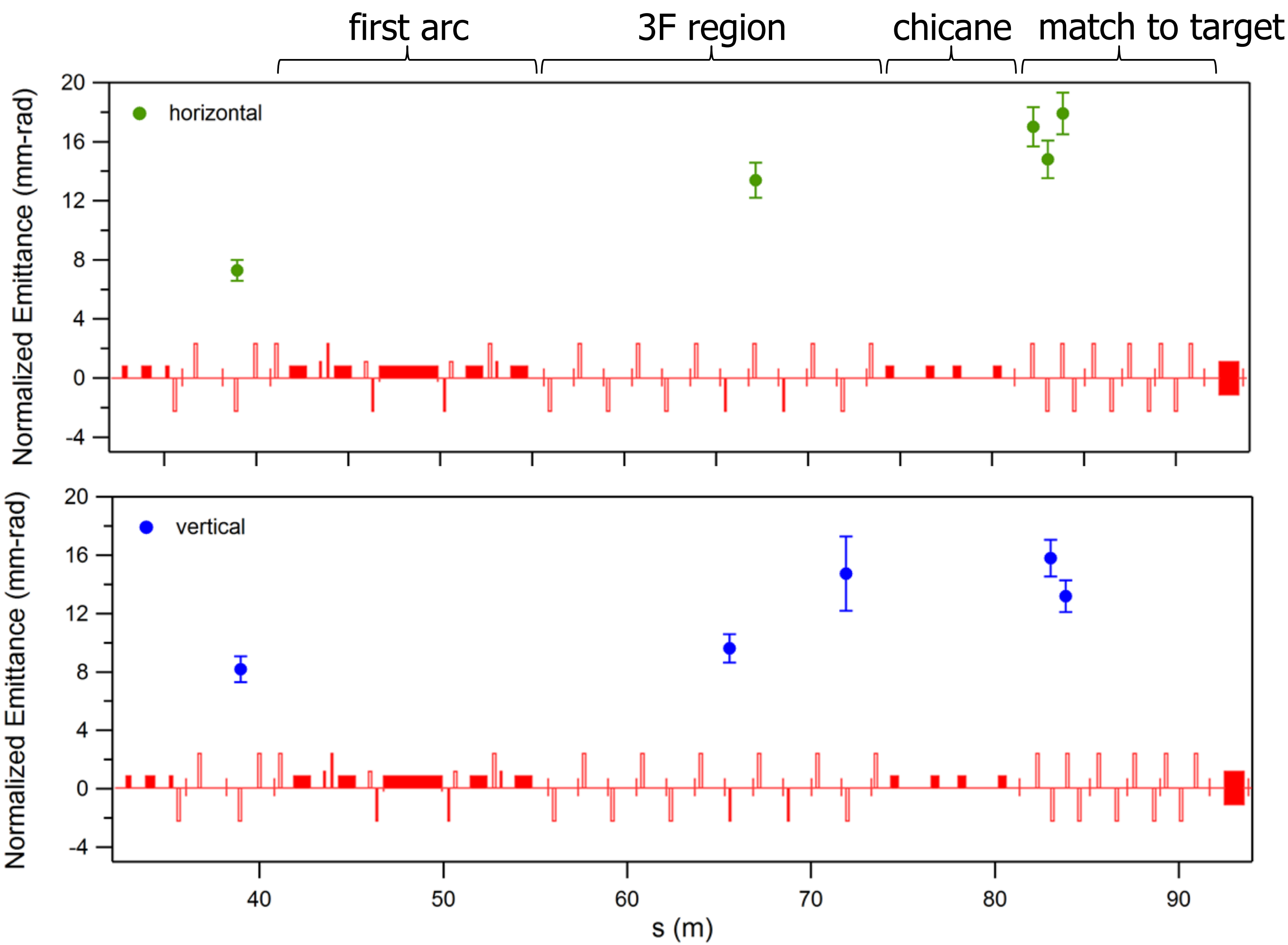
DarkLight: Target Run (2016)

- **Goal: run power with internal gas target**
- little over 2 weeks between runs
- matched beam to solenoid
- target baffles misaligned → poor transmission
- machine ran well (RF, gun, drive laser, most diagnostics)
- gas target ran stably at 300 mTorr
  - ✓ no obvious effect on the beam
- MIT took data with and without gas at various magnet strengths



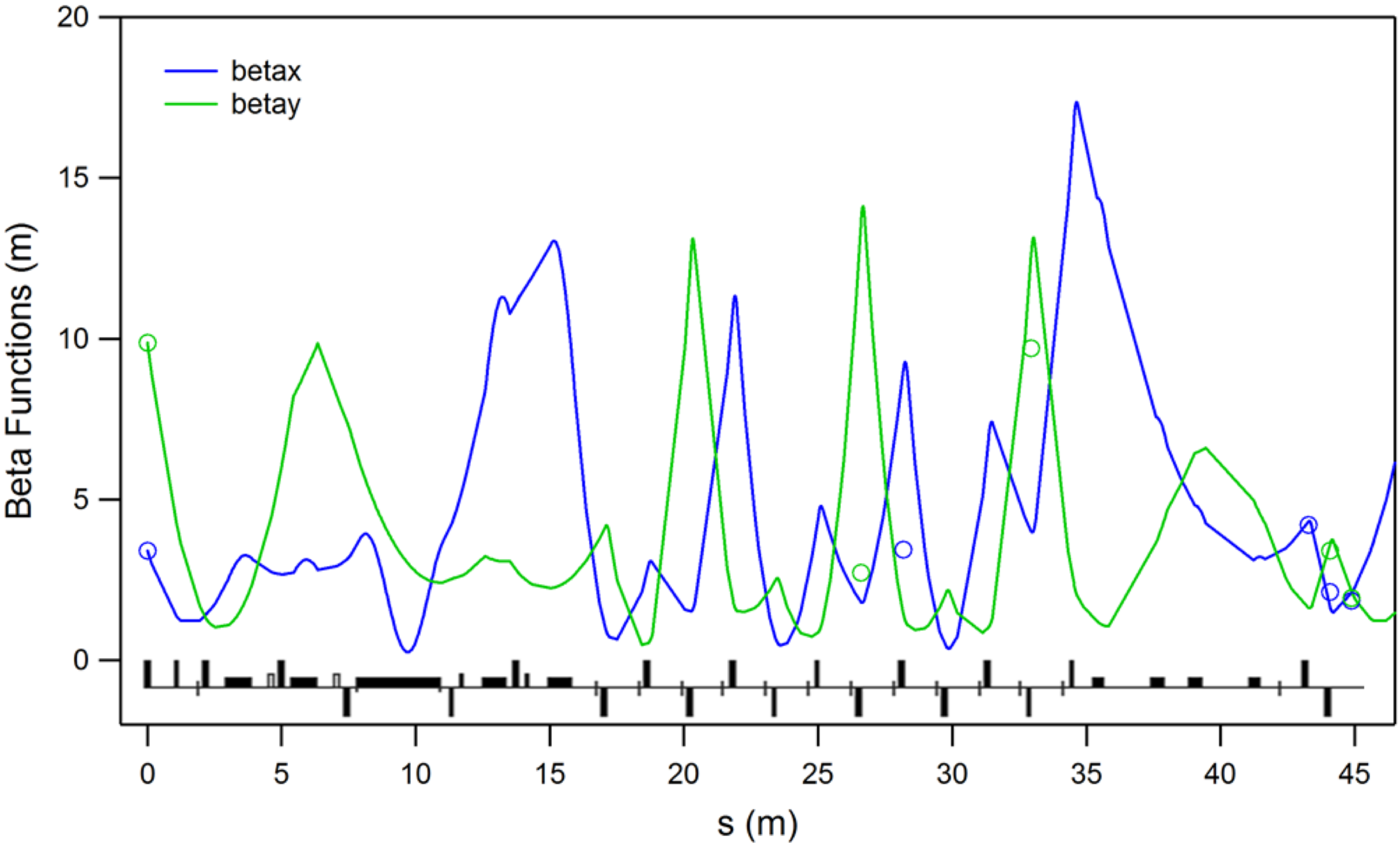
Beam Characterization

- results of quadrupole scans at various locations in the machine



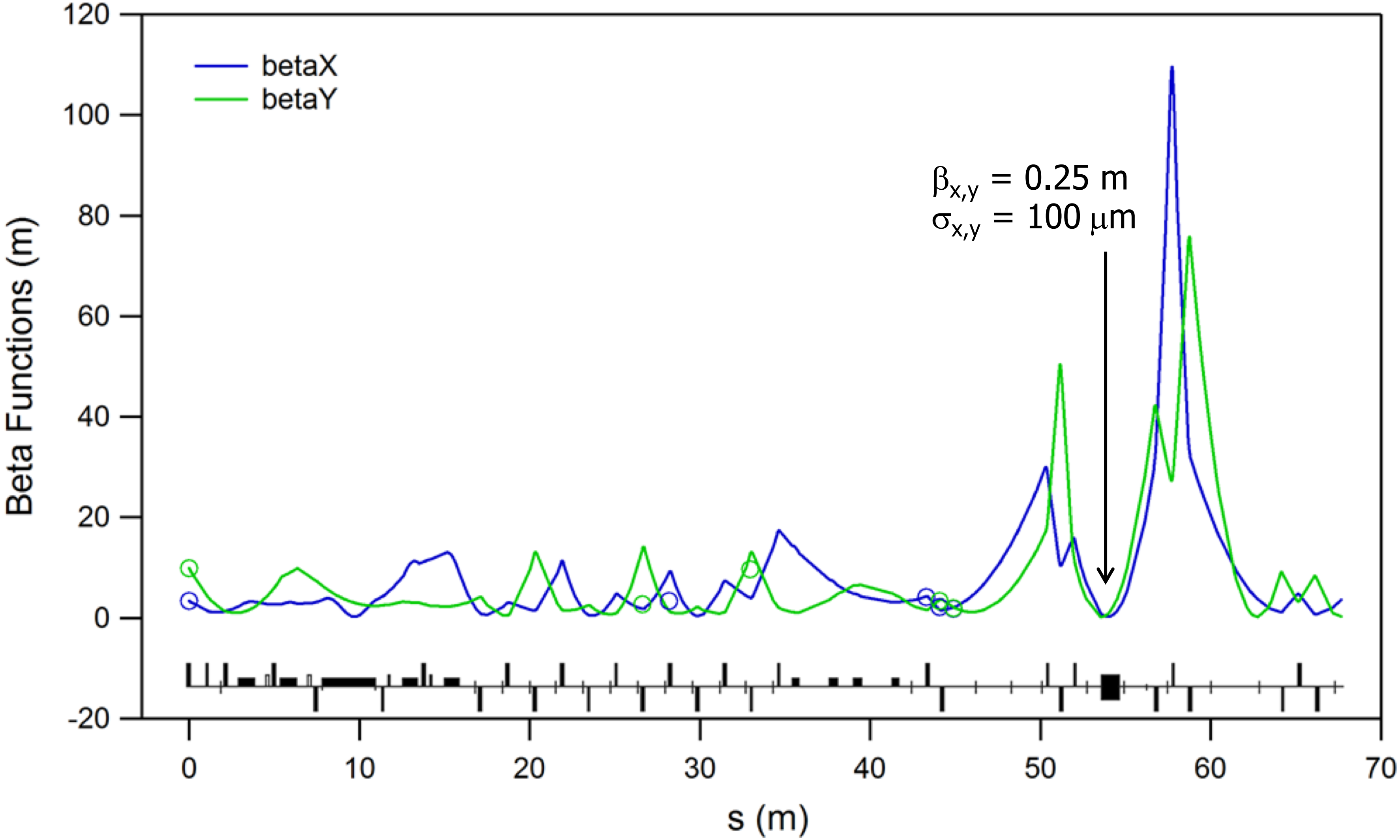
Beam Characterization

- propagating measured Twiss parameters through DarkLight target



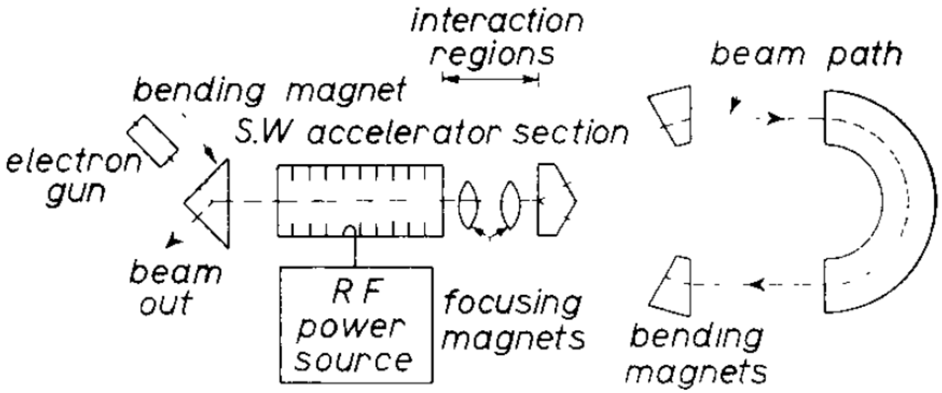
Beam Characterization

- propagating measured Twiss parameters through DarkLight target



Summary

- lessons learned
  - ✓ aggressive schedule (operations and installation)
    - *shortened from initial plan → no contingency*
  - ✓ operations learning curve
  - ✓ software issues (magnet settings)
  - ✓ hardware issues (diagnostics, solenoid, target baffles)
- **but, could run beam to target with thickness 10^{18} cm^{-2}**
  - ✓ 3 orders of magnitude larger thickness than previously demonstrated



"The energy recovery technique might also be useful in experiments other than clashing beam type. For instance a low-density target such as liquid hydrogen might be placed in the return leg of the magnet system."
M. Tigner, Nuovo Cimento (1965)

Looking Forward

- **DarkLight**
  - ✓ not clear…

U.S. Cosmic Visions: New Ideas in Dark Matter

23-25 March 2017 *Stamp Student Union, University of Maryland, College Park*

"Input is requested on the possibilities for small (the whole project is $10M or less) dark matter projects in unexplored parameter space."

- **JLEIC**
  - ✓ design of single pass ERL cooler
  - ✓ design of multi-turn CCR cooler
  - ✓ demonstration of CCR using LERF infrastructure

Report of the Community Review of EIC Accelerator R&D for the Office of Nuclear Physics

February 13, 2017

2017

- **Other**
  - ✓ medical isotope production
  - ✓ low energy target irradiation
  - ✓ intense positron source

WORKSHOP ON SCIENCE AT LERF

March 2017

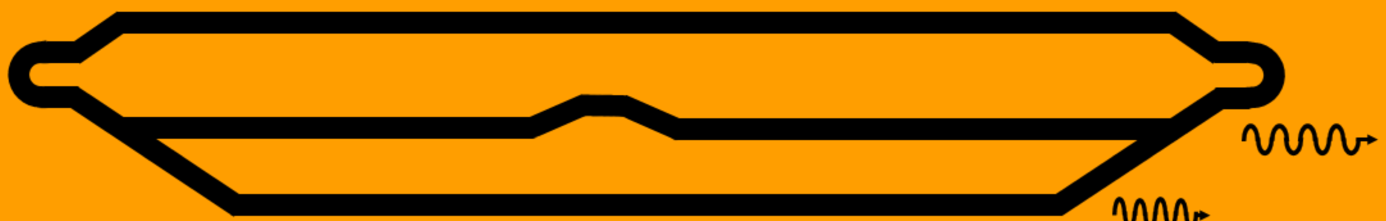
ACKNOWLEDGEMENTS

DarkLight Collaboration
Operations Staff

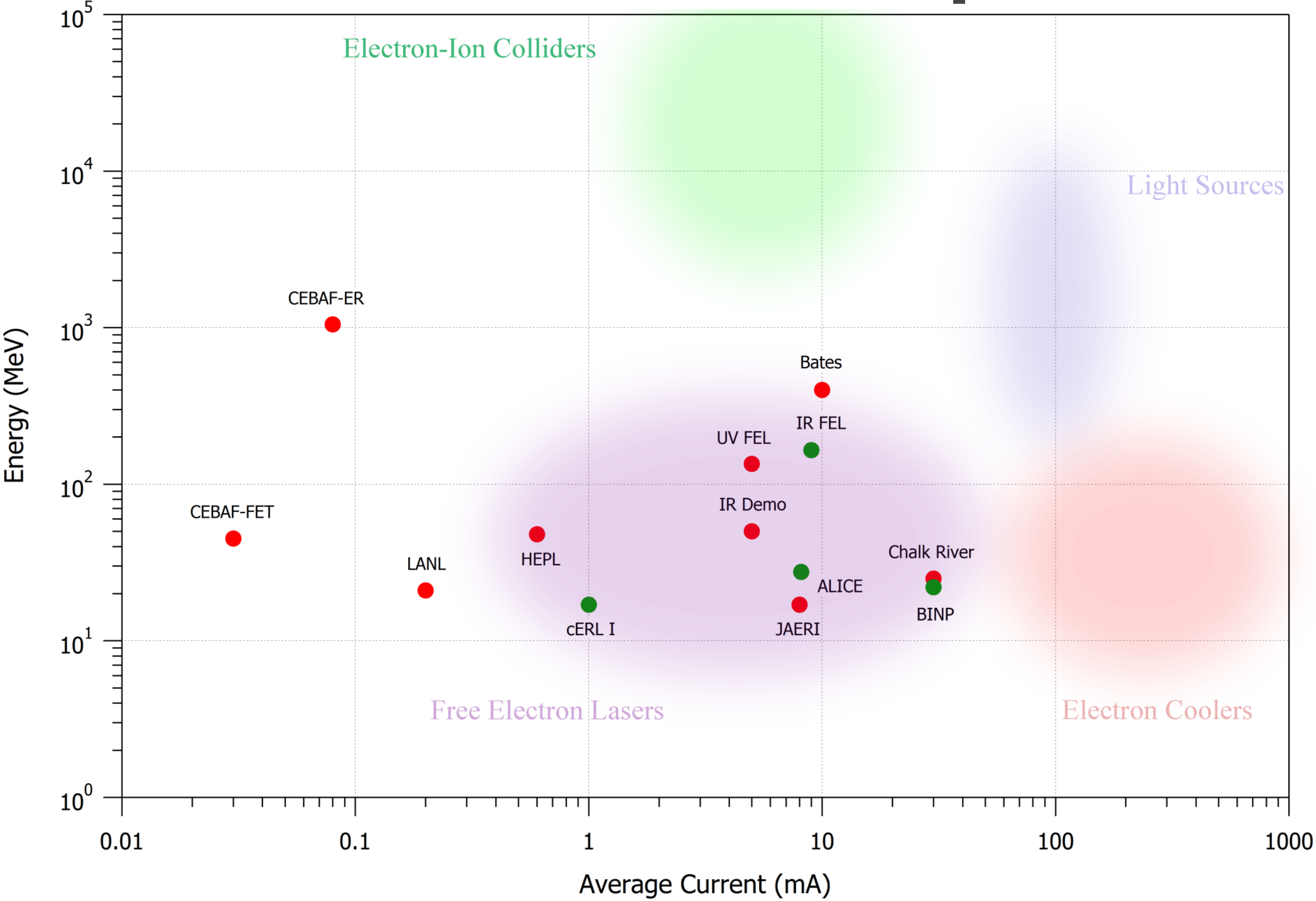
And in particular:

Steve Benson
David Douglas
Pavel Evtushenko
Bob Legg
Yves Roblin
Todd Satogata
Mike Spata
Mike Tiefenback

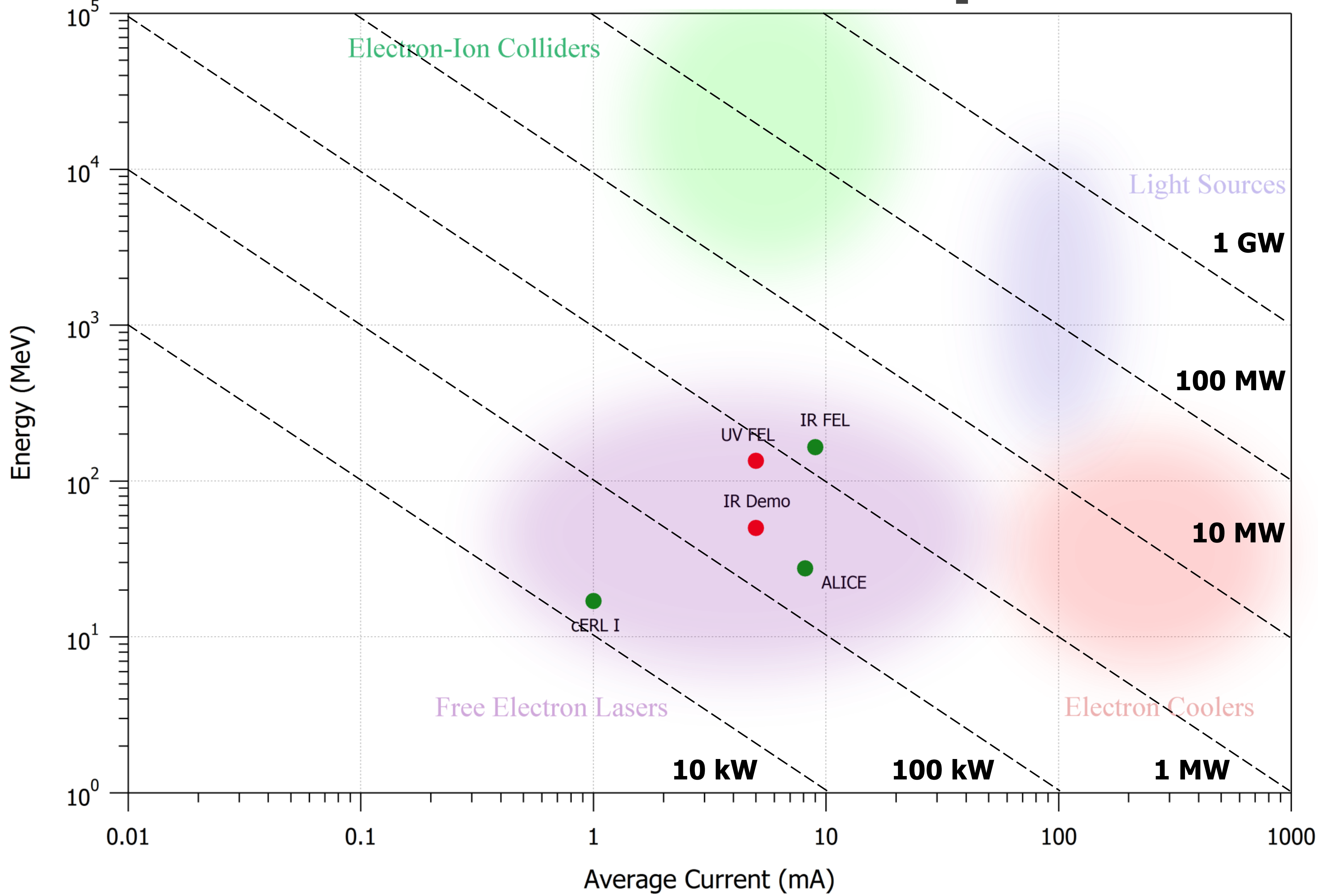
THANK YOU



Global ERL Landscape

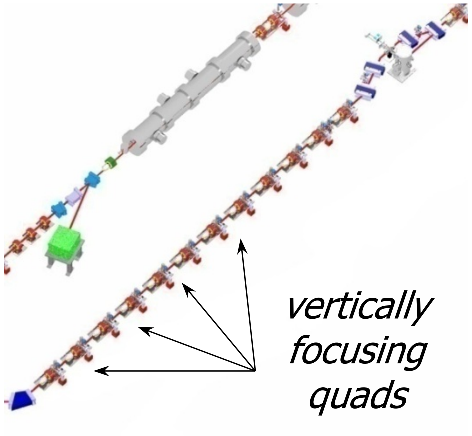


Global ERL Landscape

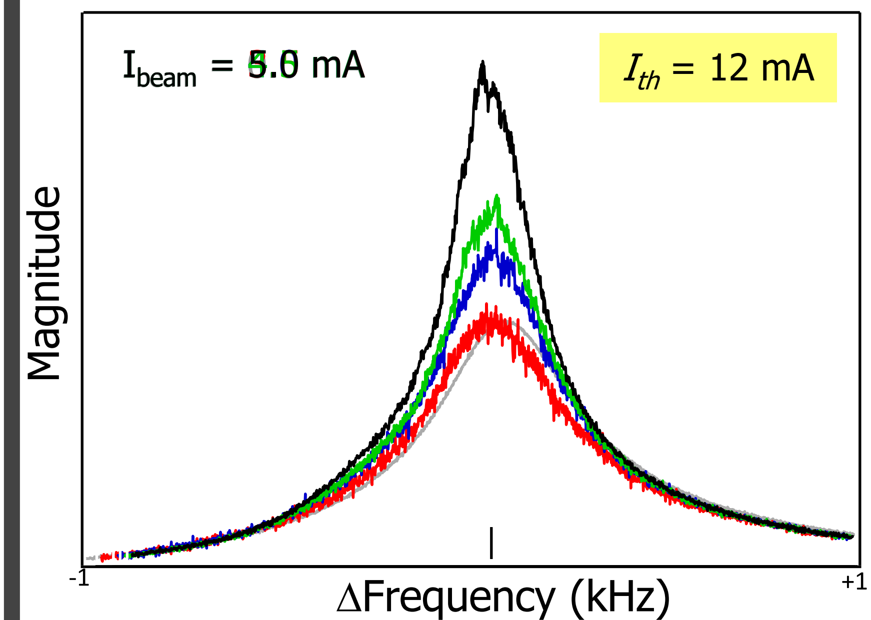


BBU Suppression Techniques

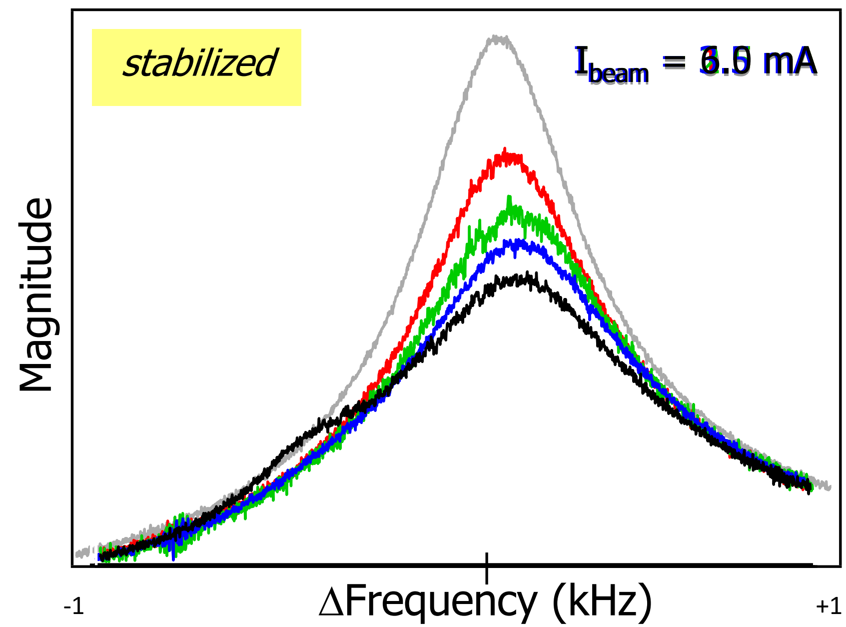
- Modify betatron phase advance → point-to-point focusing
- Change four vertically focusing quadrupoles in recirculator to vary the vertical phase advance



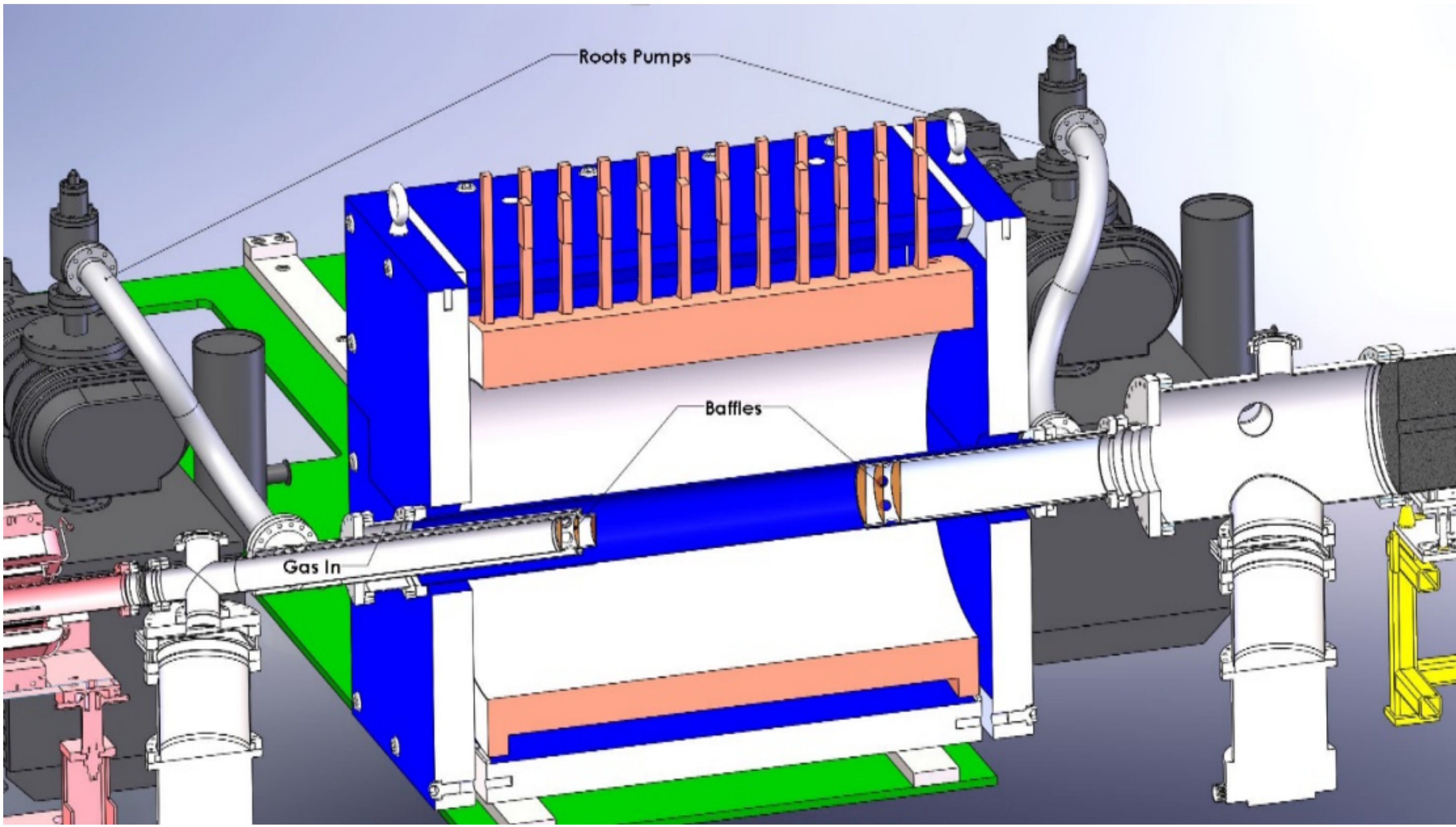
Quads changed +200 G



Quads changed +300 G

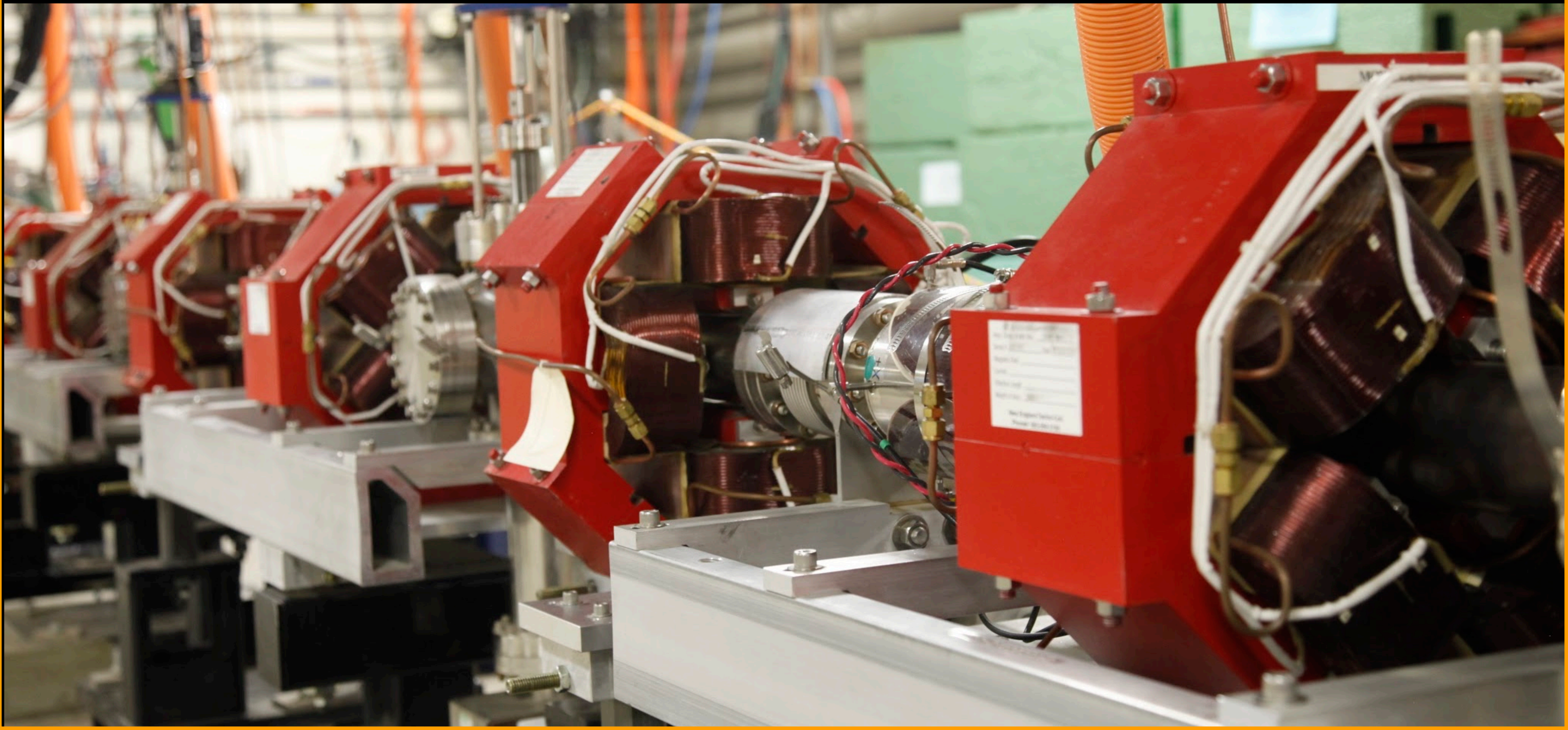


Detecting **A** **R**esonance **K**inematically with e**L**ectrons **I**ncident on a **G**aseous **H**ydrogen **T**arget

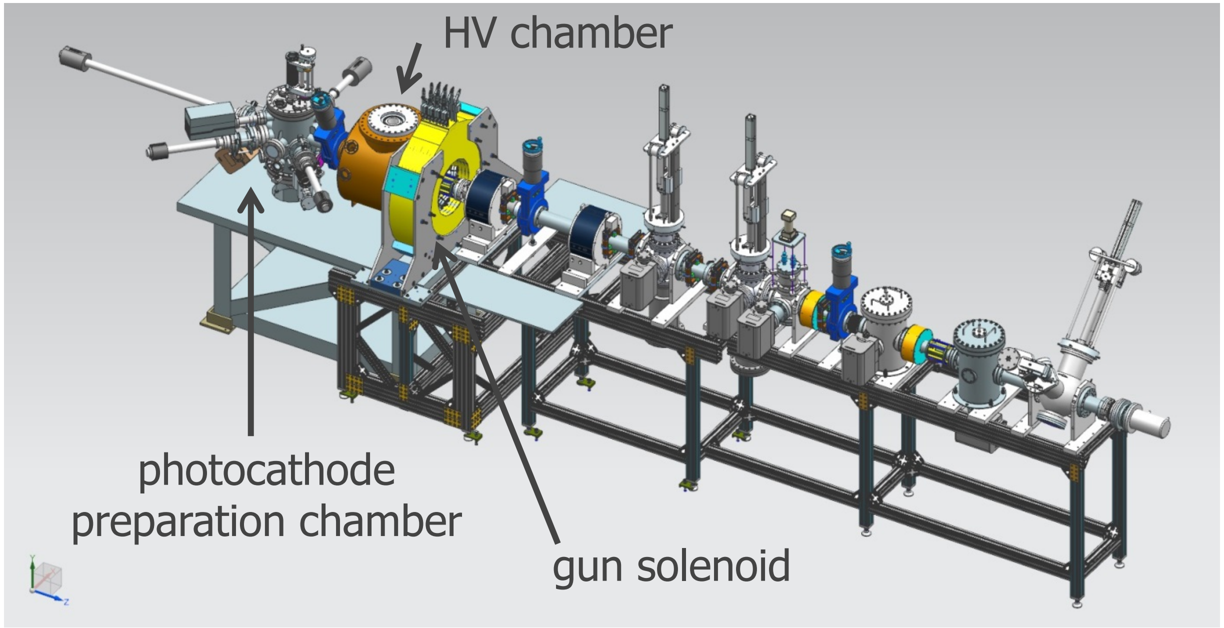


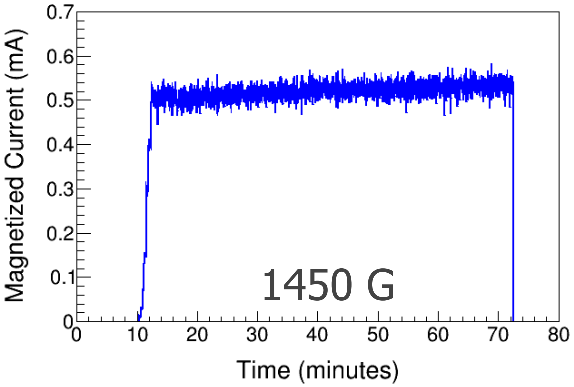
“She may not look like much, but she's got it where it counts, kid."

"She may not look like much, but she's got it where it counts, kid."



Generating a Magnetized Beam





measuring beam angular momentum (beam magnetization) using slit and viewer screen method with 1450 G at photocathode