FEL Beam Polarization Control
in a Storage Ring FEL

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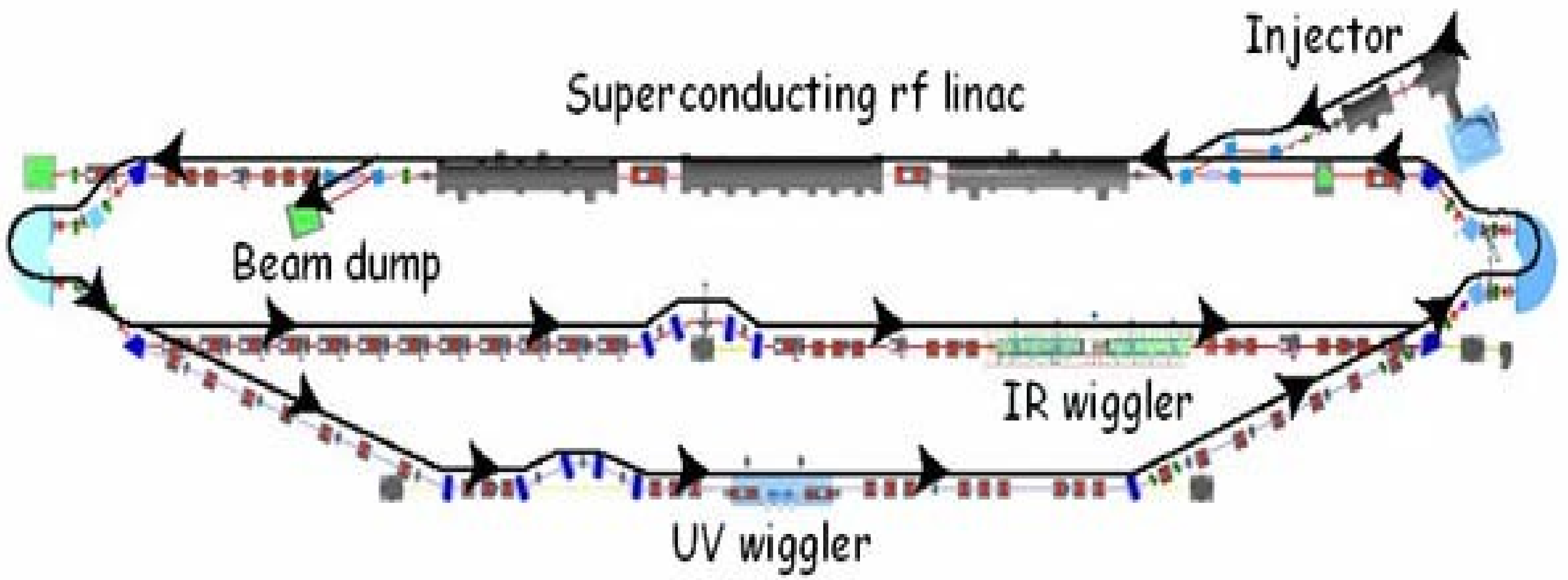
Outline

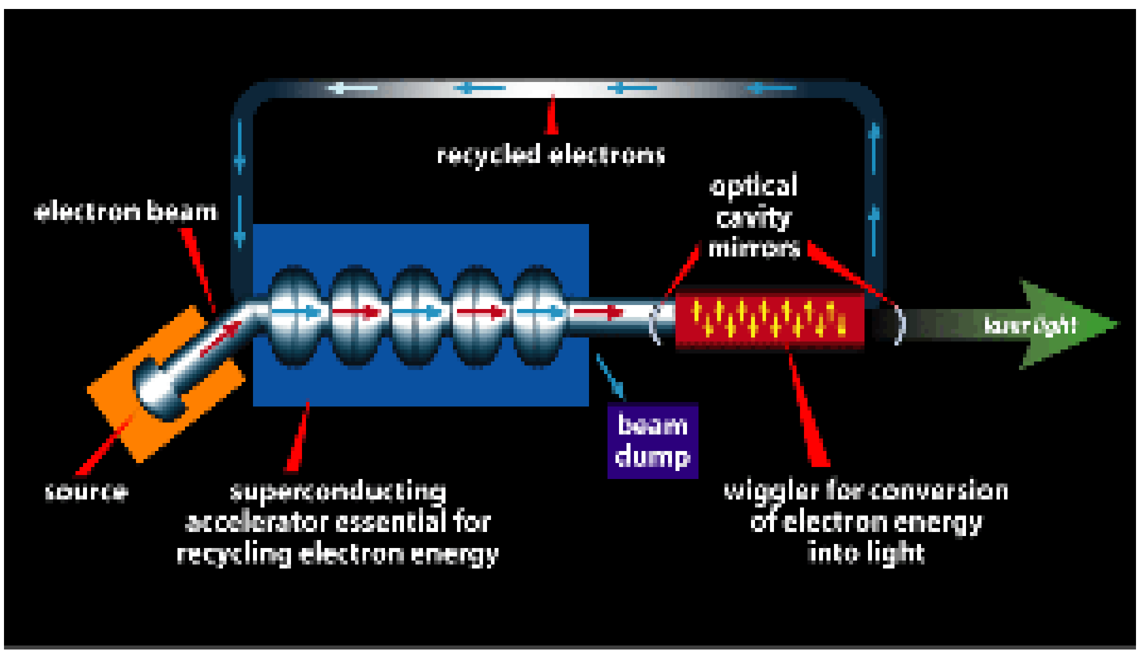
- Introduction: FELs and Polarization of Light
- Polarized FEL Beams with Linear/Helical Wigglers at Duke
  - Linear Polarization: OK-4 FEL; Circular Polarization: OK-5 FEL
  - High-current Operation with Helical FELs
  - Slow Helicity Switch
- Controlling and Manipulating FEL Polarization States
  - Fast Helicity Switch
  - Rotatable Linear Polarization using Helical Wigglers
- Exploring and Exploiting Polarization Control of FELs
  - Advantages over conventional lasers: wavelength and polarization

I. Introduction:

FELs and Polarization of Light

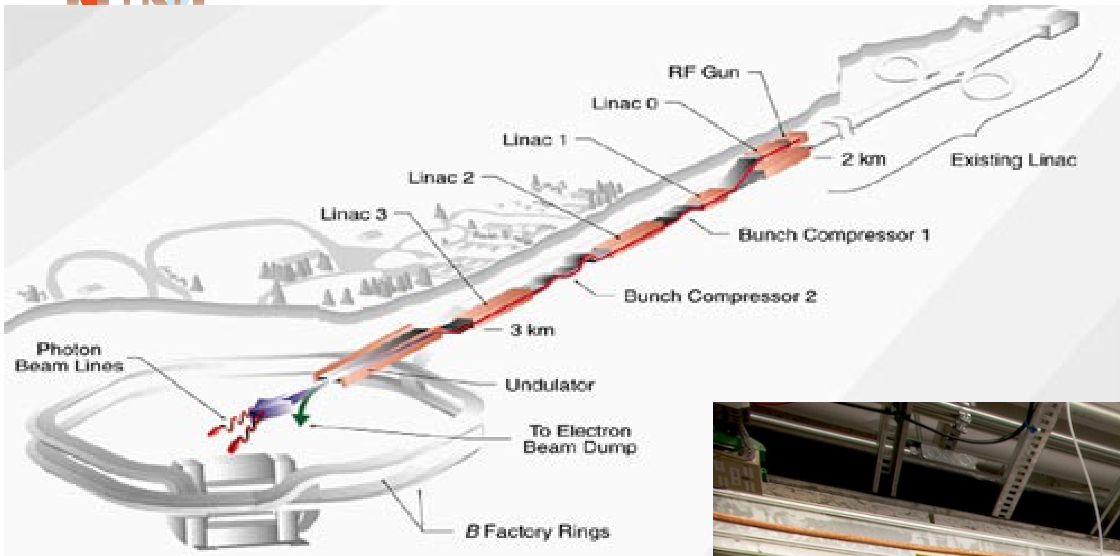
High Extracted Power : Jlab FEL

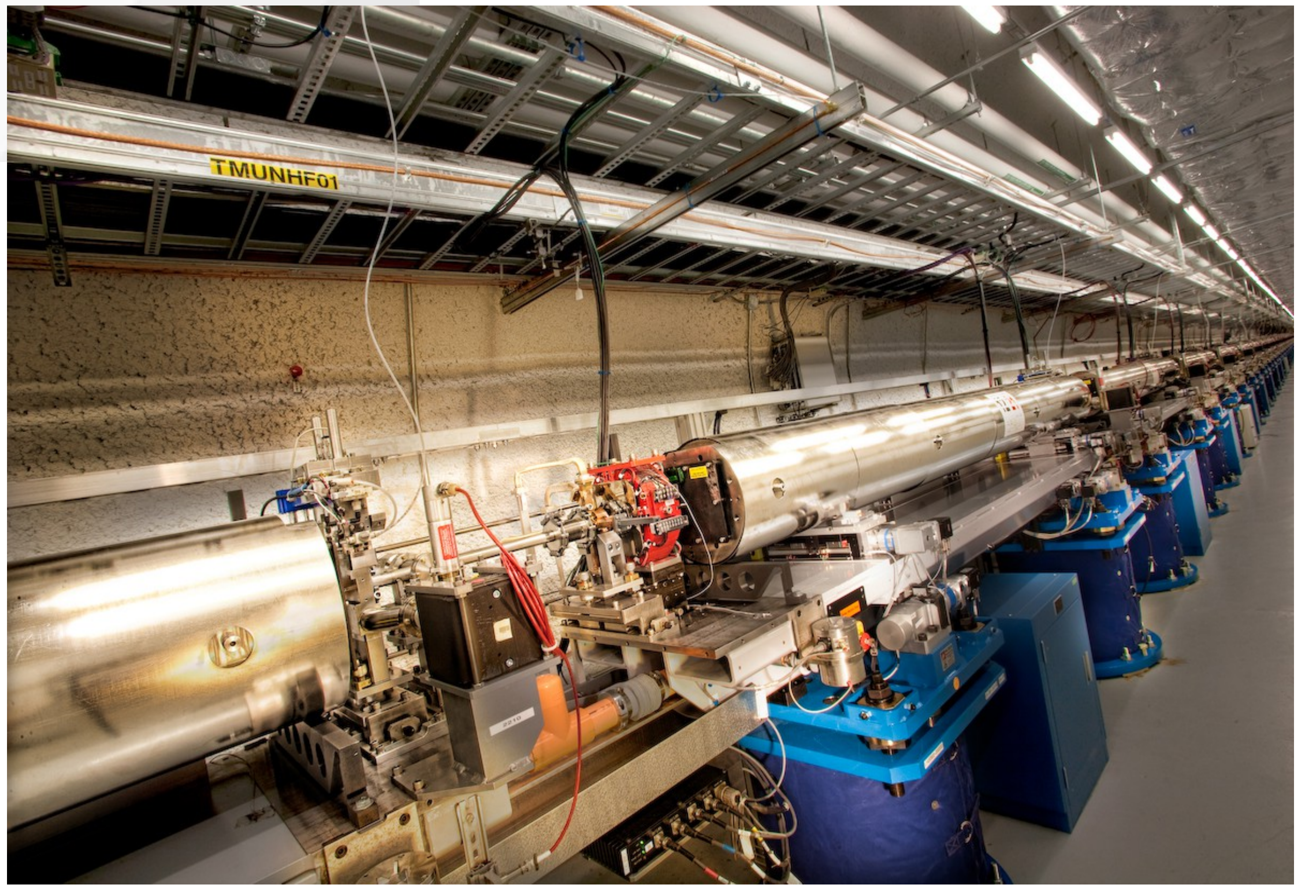




Jlab IR-FEL (2006)
> 14.2 kilowatts CW power
at 1.6 microns

Short Wavelength: LCLS, an X-ray FEL

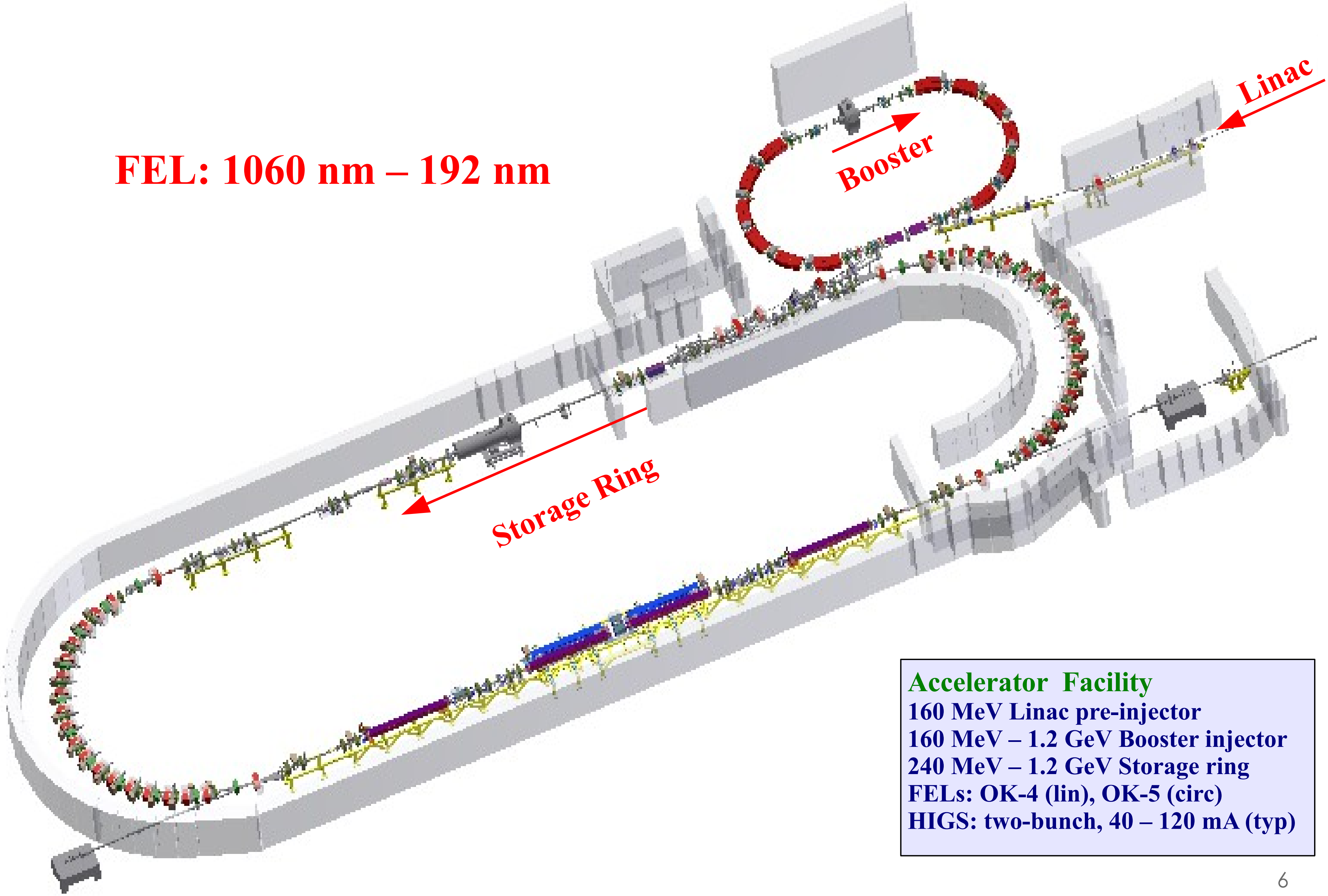




1. http://lcls.slac.stanford.edu/lcls_gallery/album1/hires/lcls_firstlight_hires-10.jpg
2. https://www2.slac.stanford.edu/tip/2002/nov1/lcls.htm

A Wide Wavelength Range: Duke Storage Ring FEL

FEL: 1060 nm – 192 nm

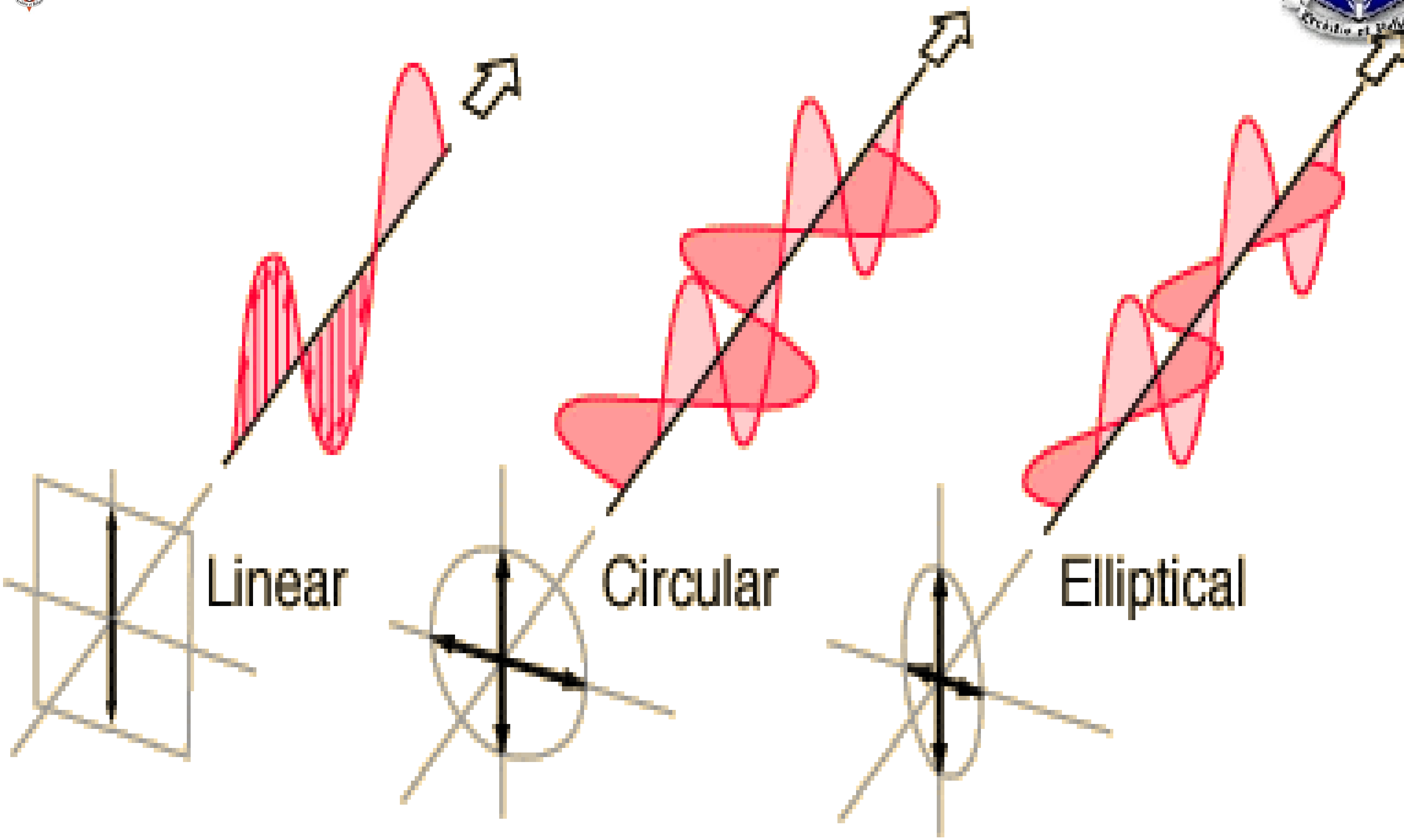


Accelerator Facility
160 MeV Linac pre-injector
160 MeV – 1.2 GeV Booster injector
240 MeV – 1.2 GeV Storage ring
FELs: OK-4 (lin), OK-5 (circ)
HIGS: two-bunch, 40 – 120 mA (typ)

Polarization in Politics

"Obama's problem of polarization", credit: Douglas; 2010/02/04
http://whitmanpioneer.com/opinion/columnists/2010/02/04/the-problem-of-polarization/

Polarization of EM-Wave: Light

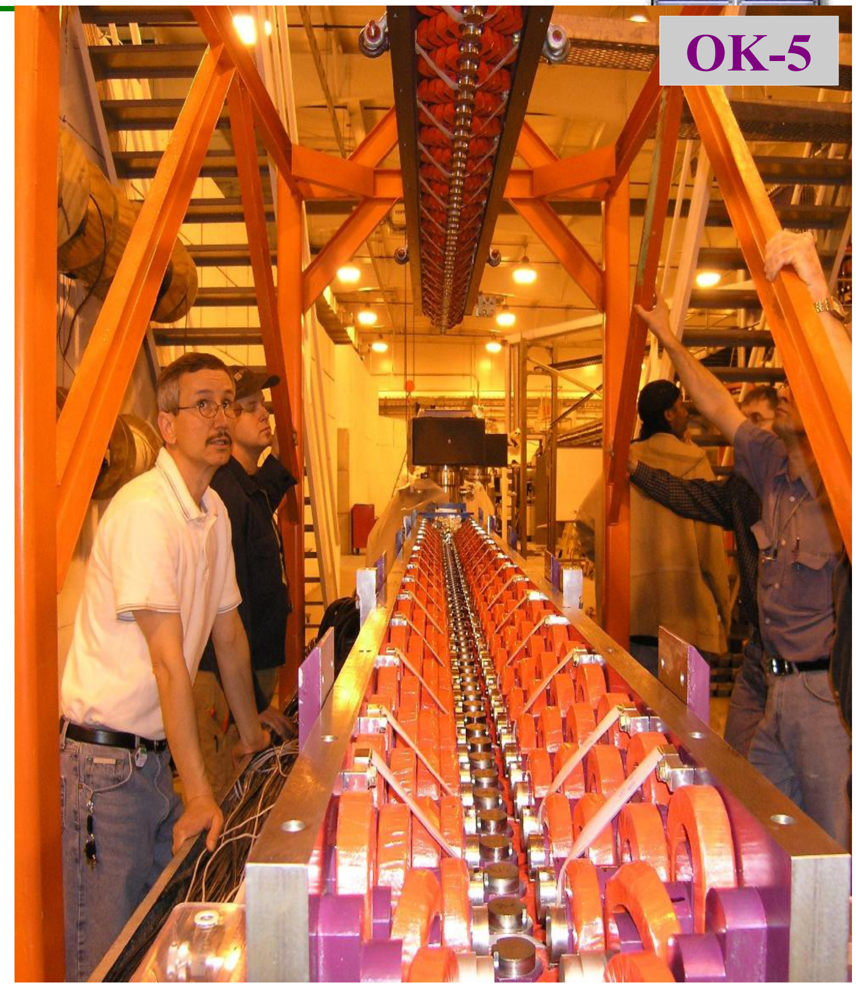


http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html

II. Polarized FEL Beams with Linear/Helical Wigglers

- **Linear Polarization: OK-4 FEL; Circular: OK-5 FEL**
- **High-current Operation with Helical FEL**
- **Slow Helicity Switch**

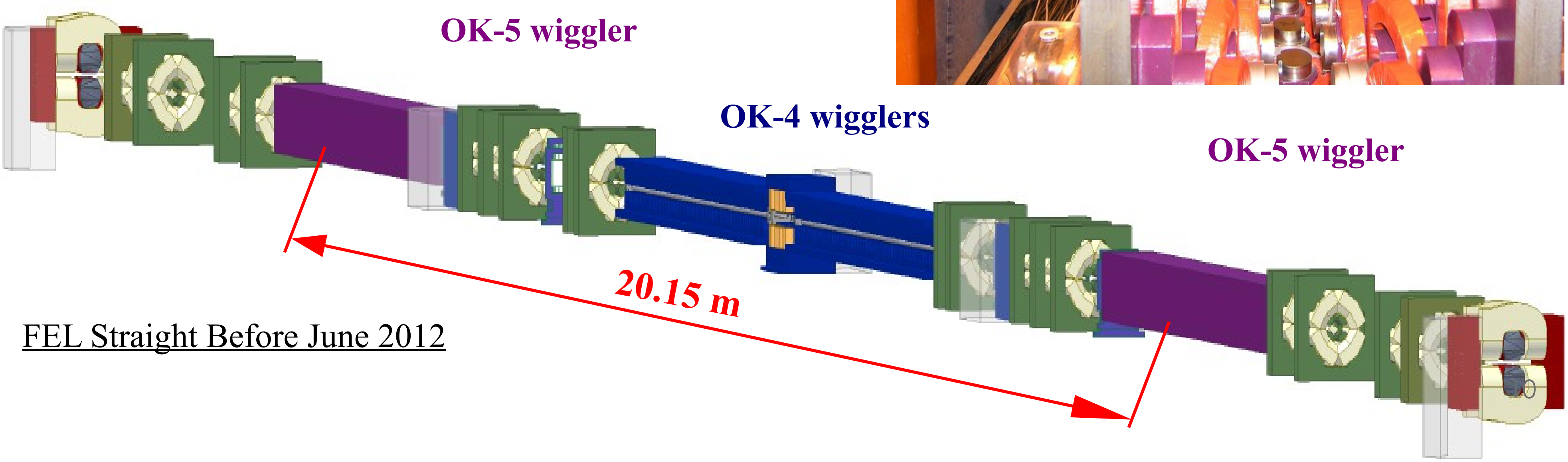
FELs with Planar and Helical FELs: OK-4 and OK-5



Electromagnetic Wigglers

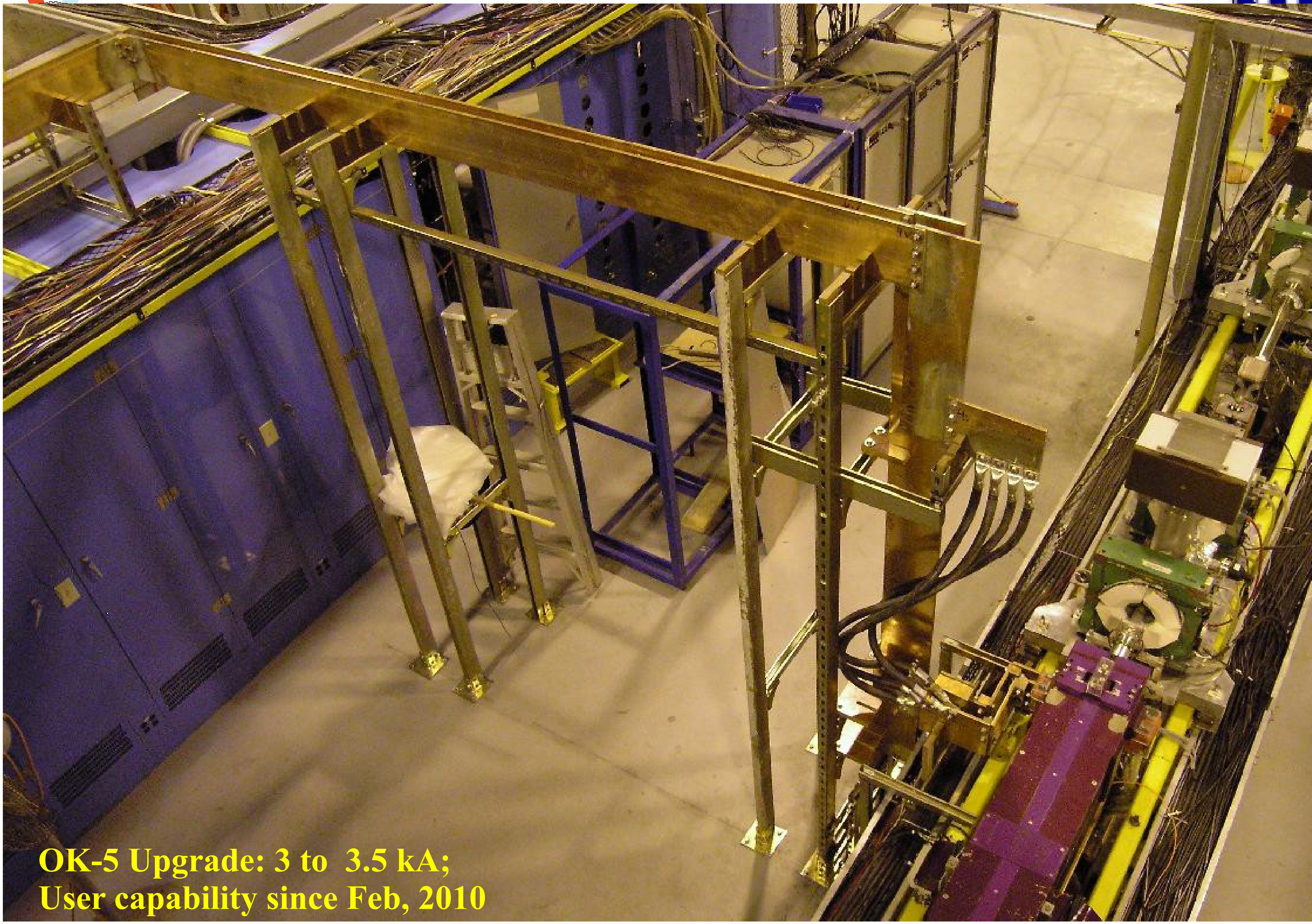
- OK-4 FEL for linear polarization
- OK-5 FEL for circular polarization

	OK-4	OK-5
Polarization	Linear	Circular
No. of reg. period	33	30
Wiggler period (cm)	10	12
Peak field (kG) at 3kA	5.36	2.86



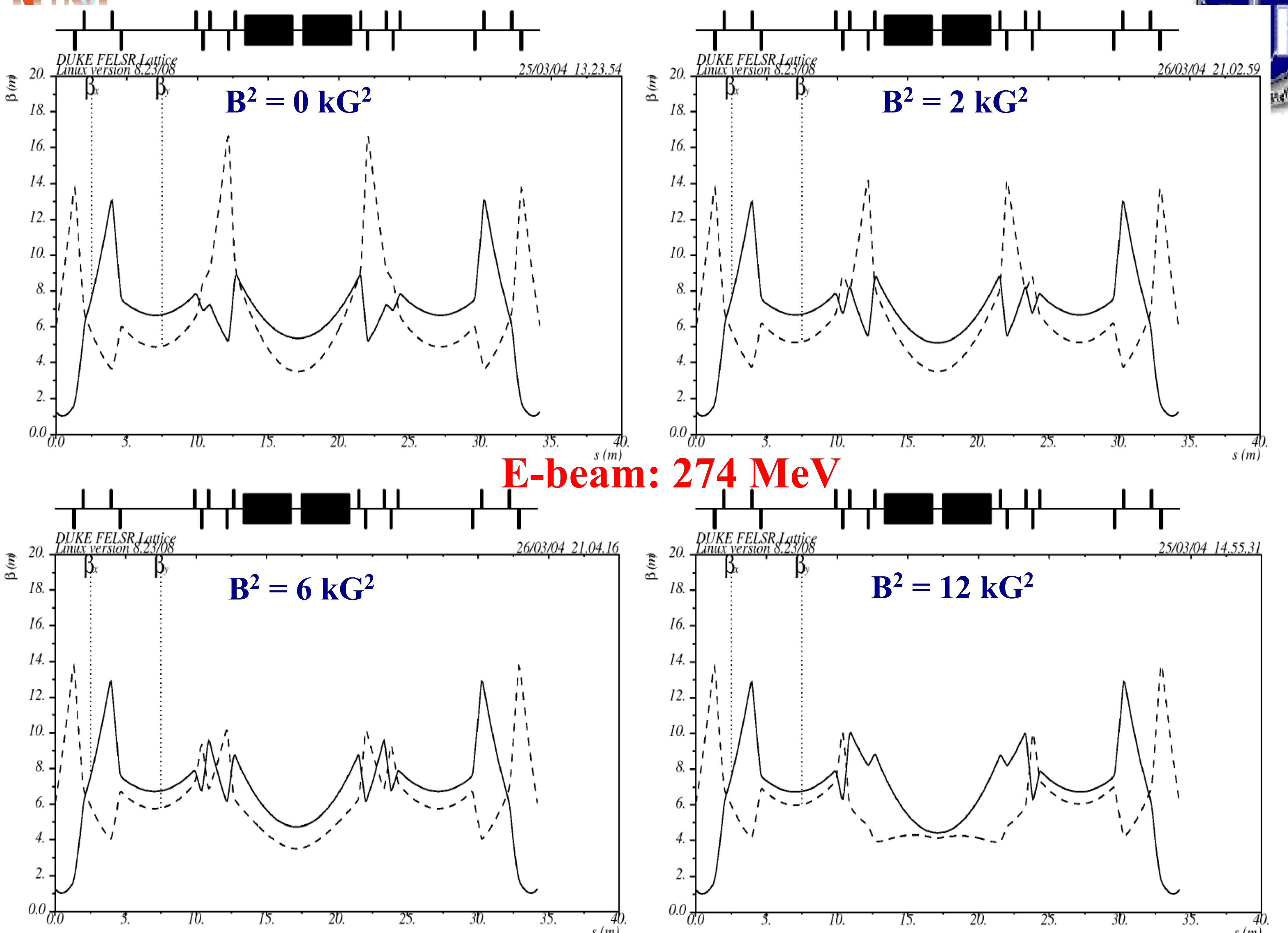
FEL Straight Before June 2012

Bussbar System: 3 kA for OK-4, 3.5 kA for OK-5



T-Rex Power Supplies for Wigglers

Wiggler Compensation: OK-4

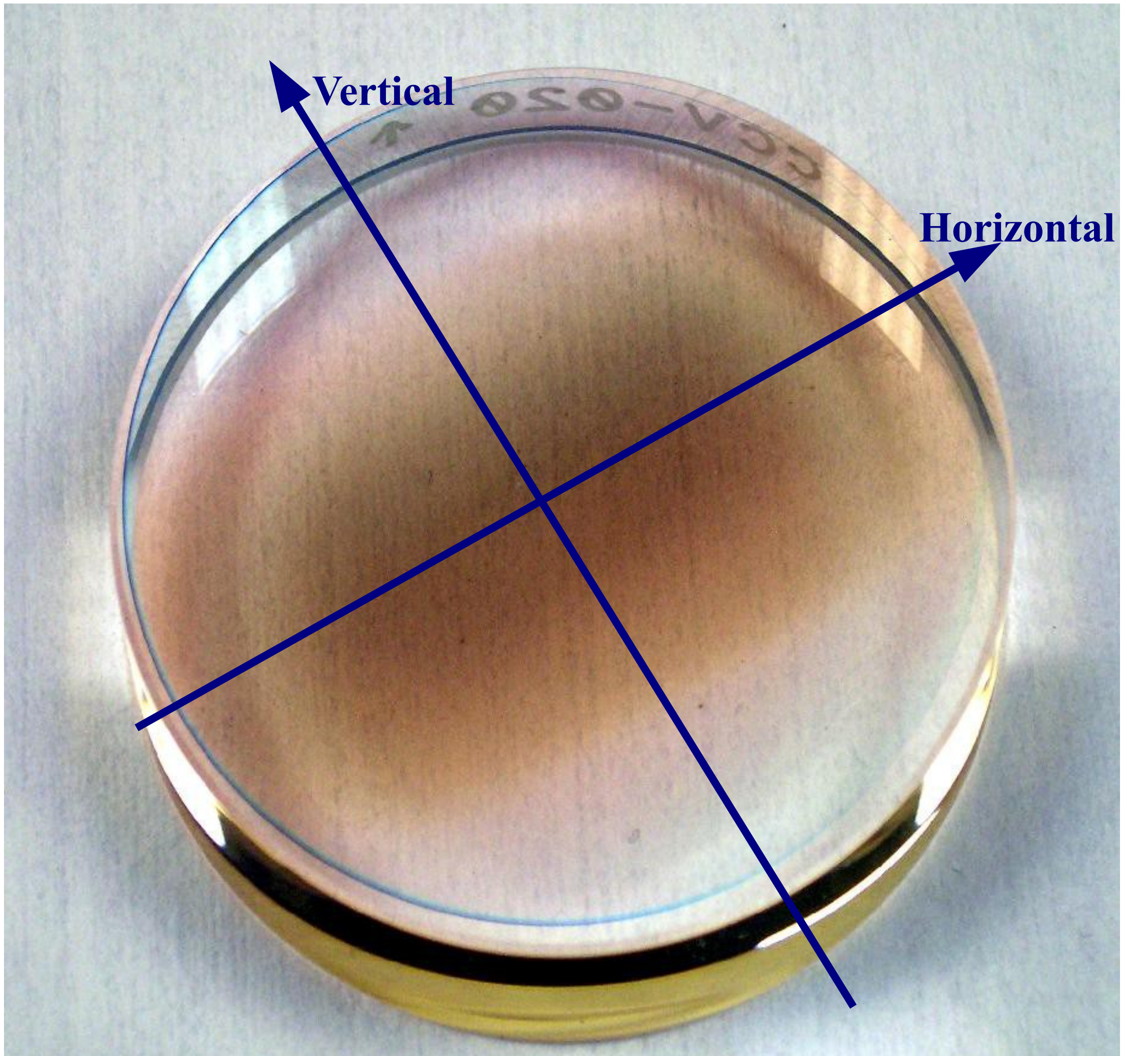


E-beam: 274 MeV

High Reflectivity FEL Mirrors

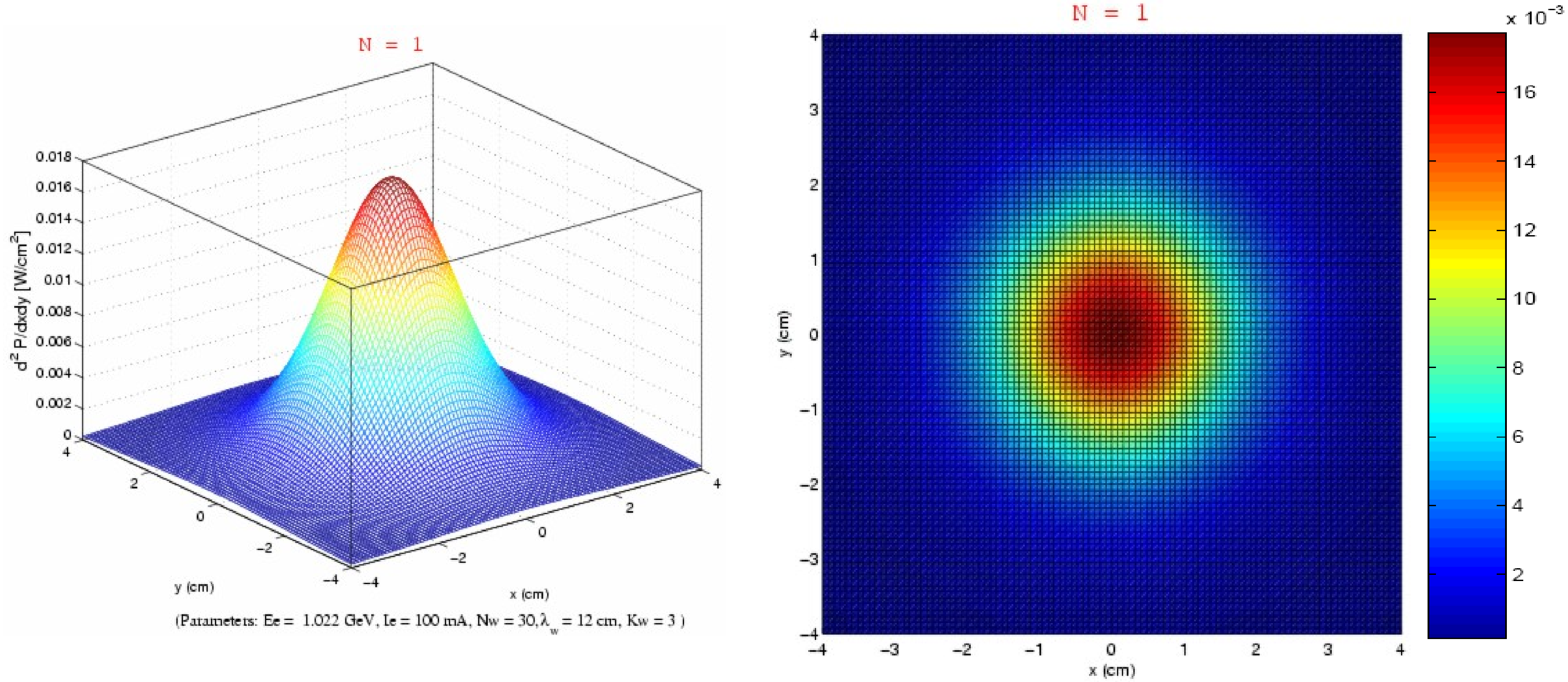
Mirror degradation

Carbon deposition on the surface



780 nm, CCV020, downstream cavity mirror, D=50 mm

Spatial Distribution of Helical Wiggler Harmonics



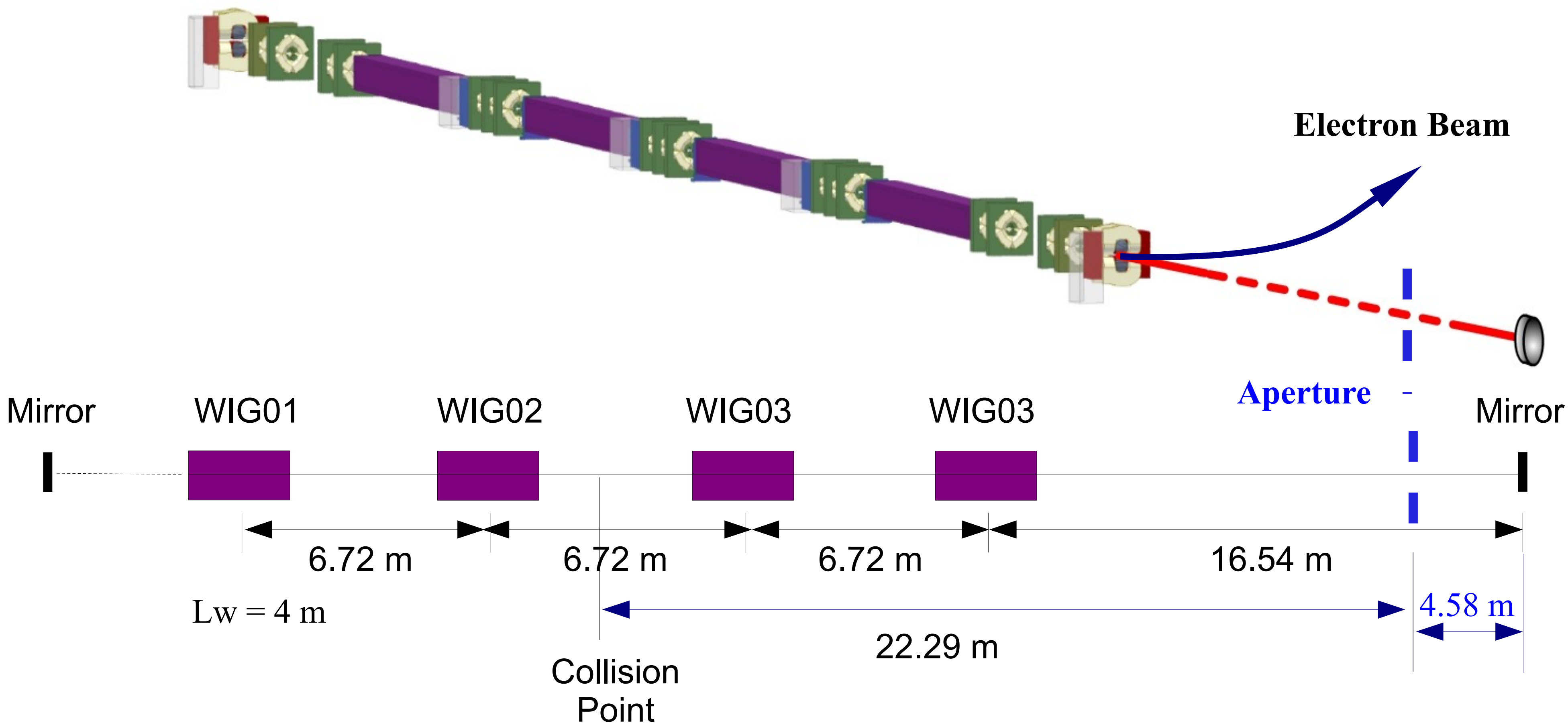
Parameters used: Ee = 1 GeV, Ie = 100 mA, Nw = 30, λw = 12 cm, Kw = 3;
Distance from wiggler center to screen is 27 m.

Improving Resonator Stability: In-cavity Apertures

Issues:

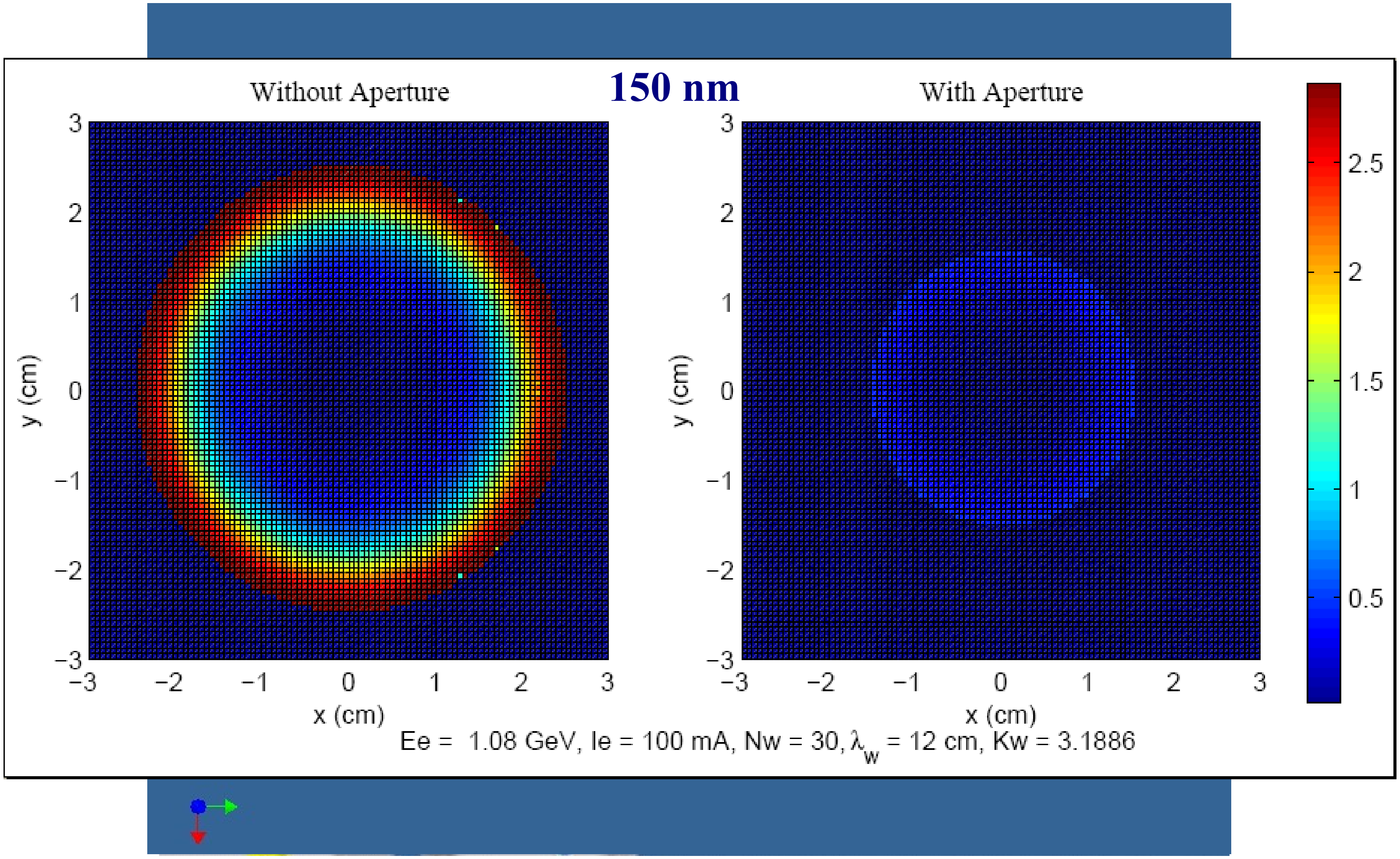
- **Mirror surface deformation (thermal)**
- **Mirror damage**

Solution: Reduce Wiggler higher-order harmonic power loading



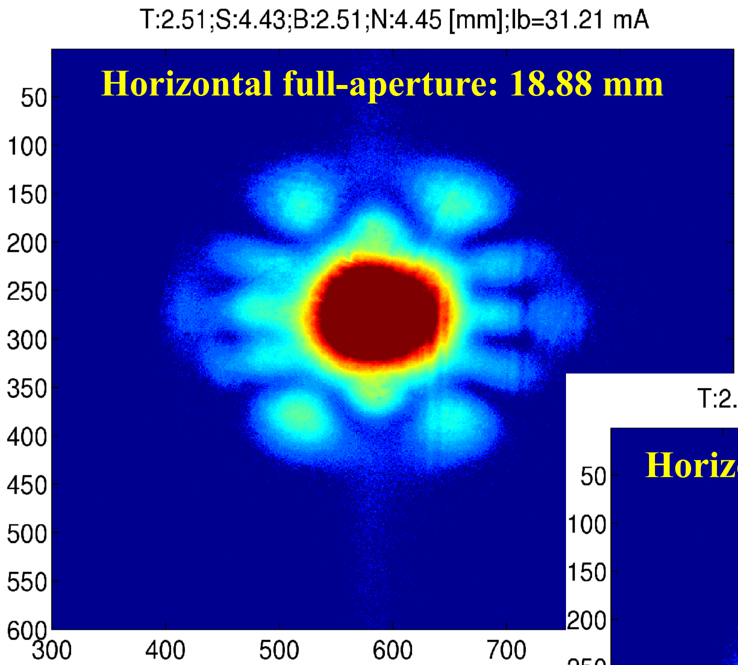
In-Cavity, Water-cooled Apertures

Harmonic Power Reduction: about two orders of magnitude

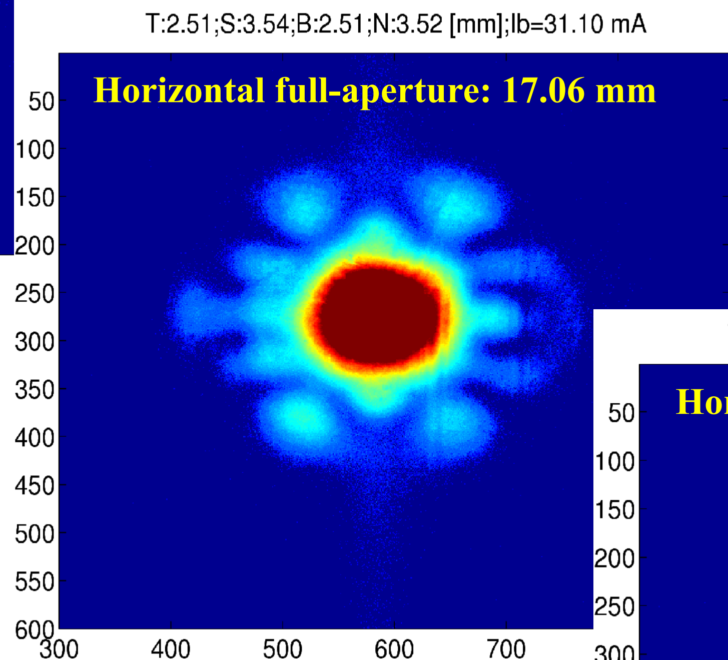


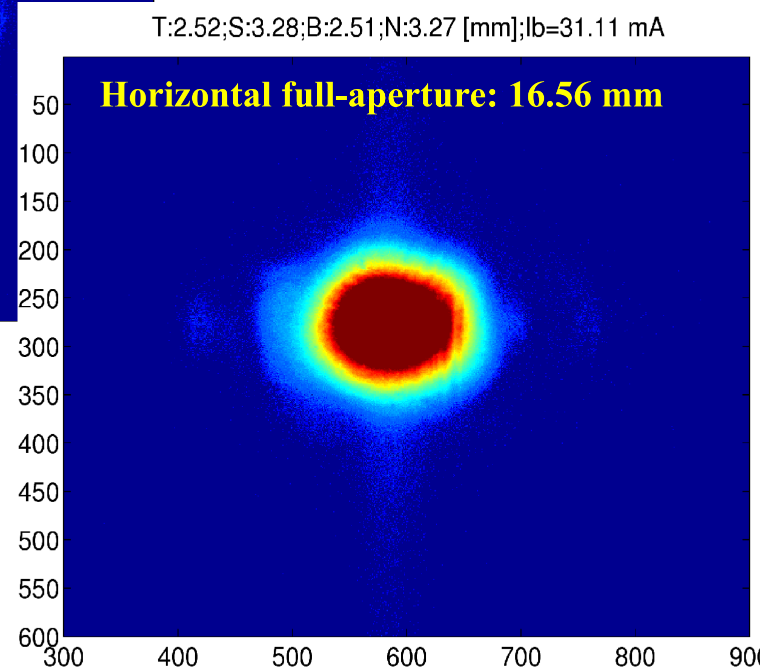
Part of Ph.D. thesis work of Senlin Huang (Beijing U./Duke, 2009)

Reducing Mirror Deformation



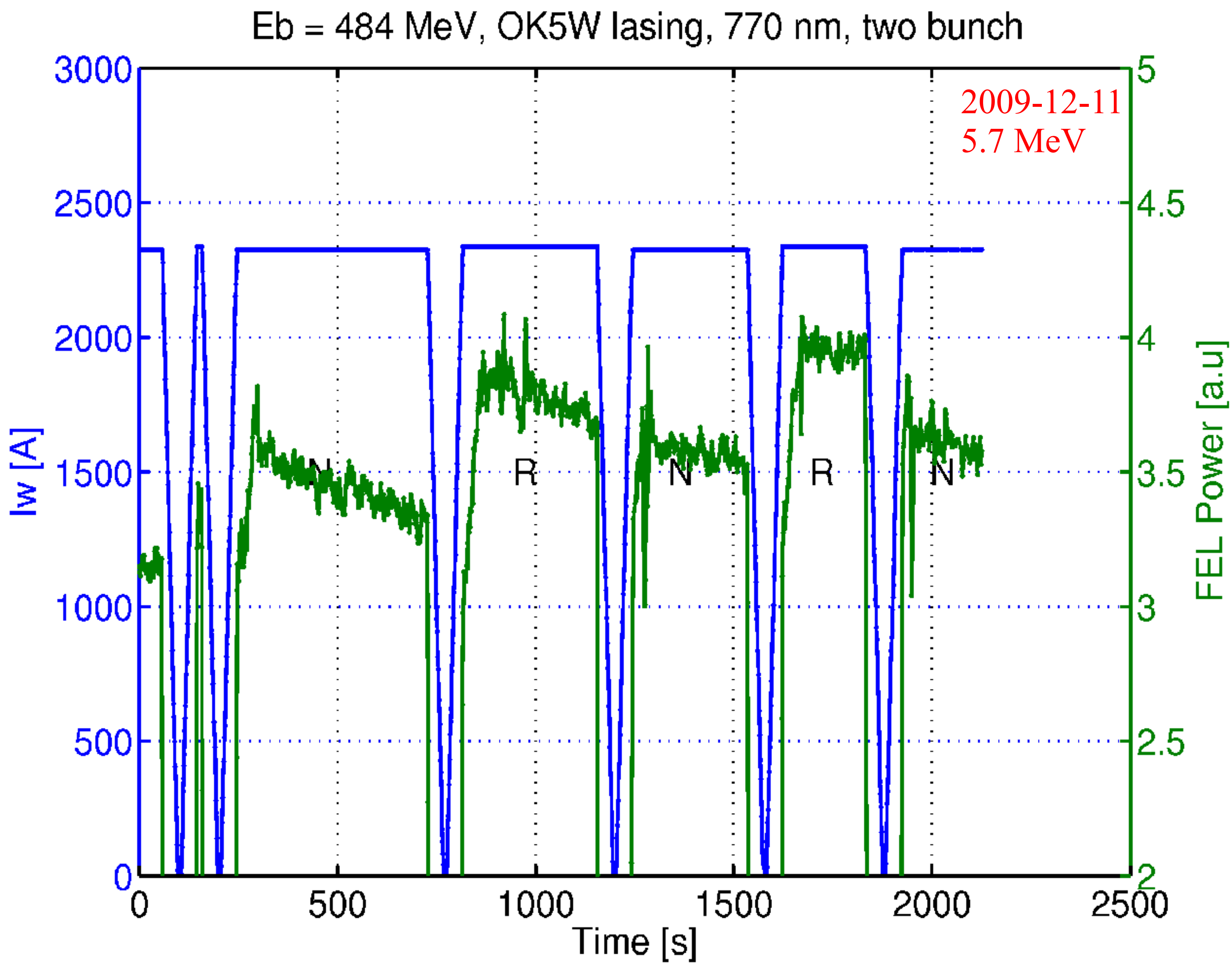
31 mA, 825 MeV 2-bunch beam, with helical OK-5 FEL



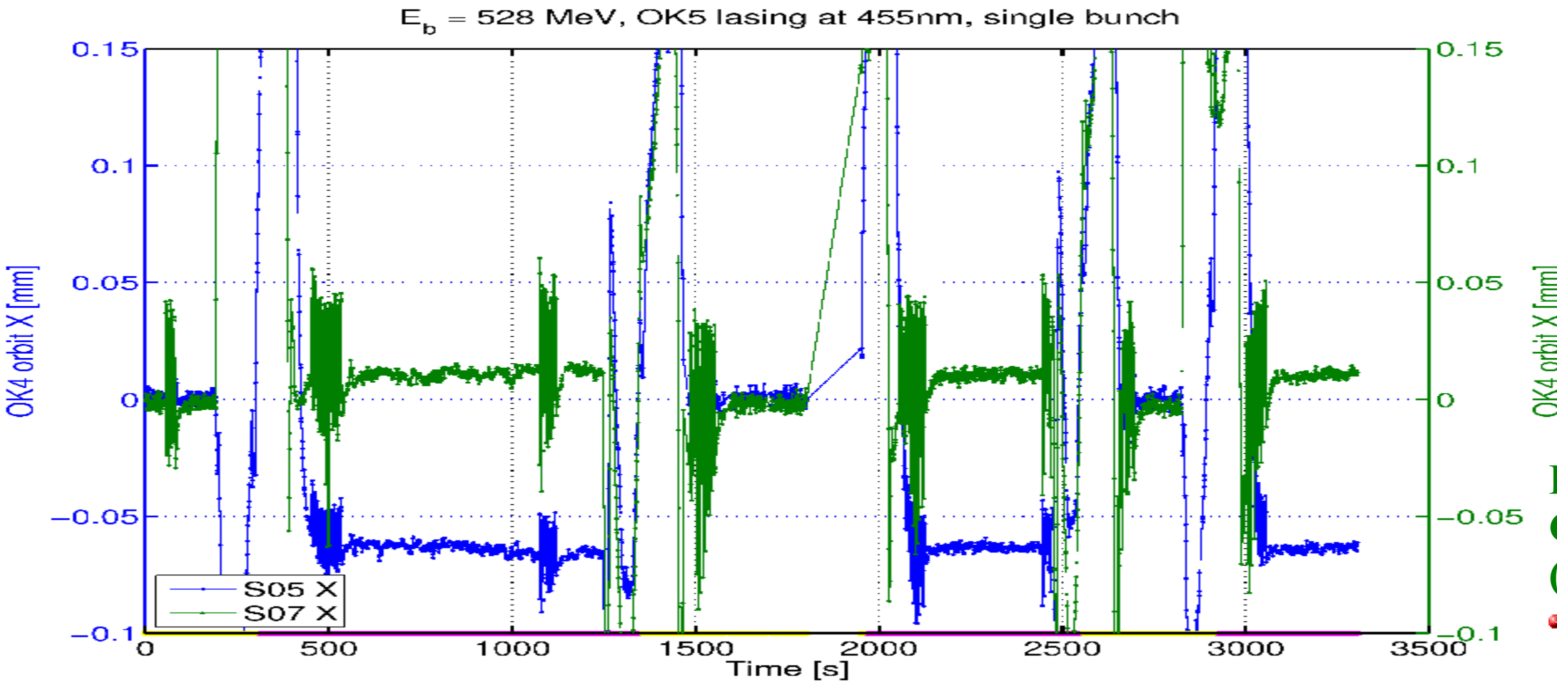


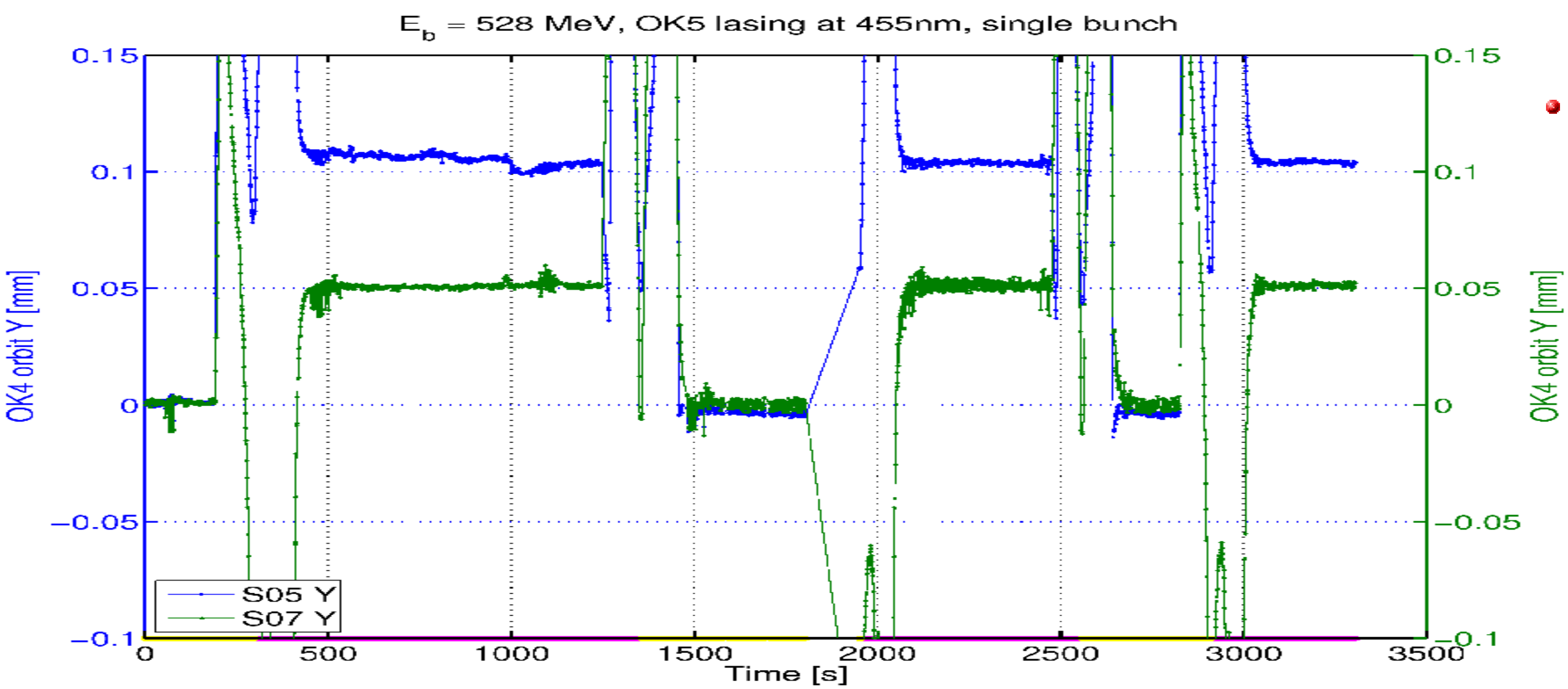
FEL transverse mode restored to TEM00 by closing the horizontal aperture

Helicity Switch Test (Dec. 2009)



Helicity Switch Test (Jan. 2011)





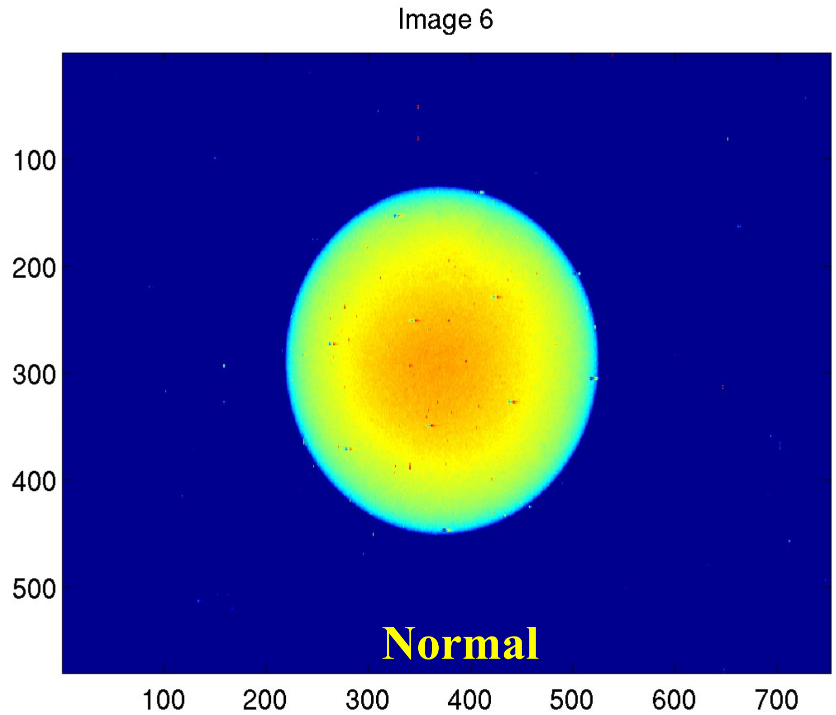
2011-01-07
11.3 MeV

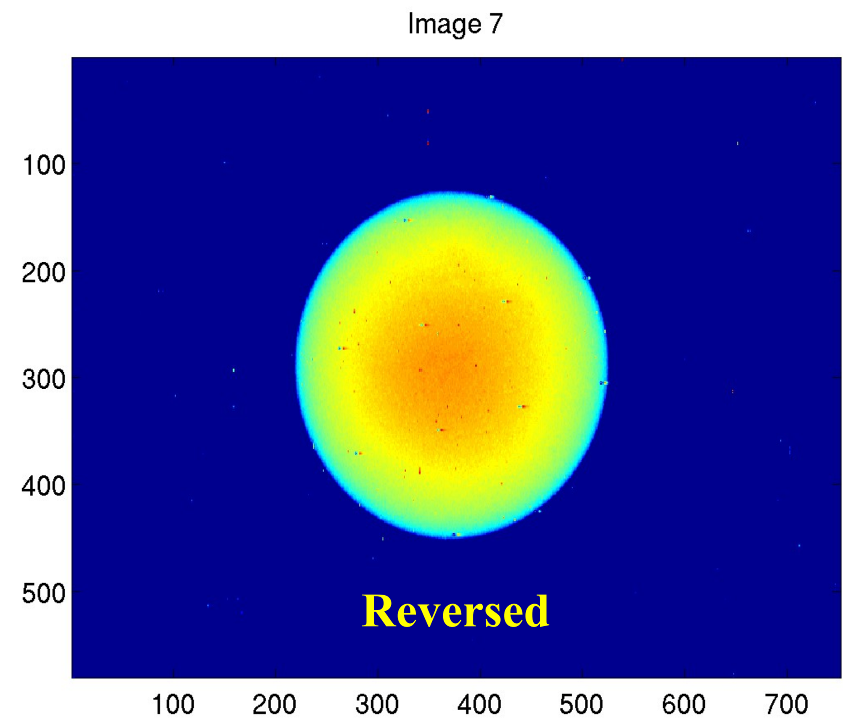
Requirements on Collision Orbit (collimator D = 12 mm)

- **Adequate**
  - **Offset: 1.2 mm**
  - **Angle: 23 µrad**
- **Desirable**
  - **Offset: 0.6 mm**
  - **Angle: 11 µrad**

Beam Aiming Consistency: γ–Images with Helicity Switch

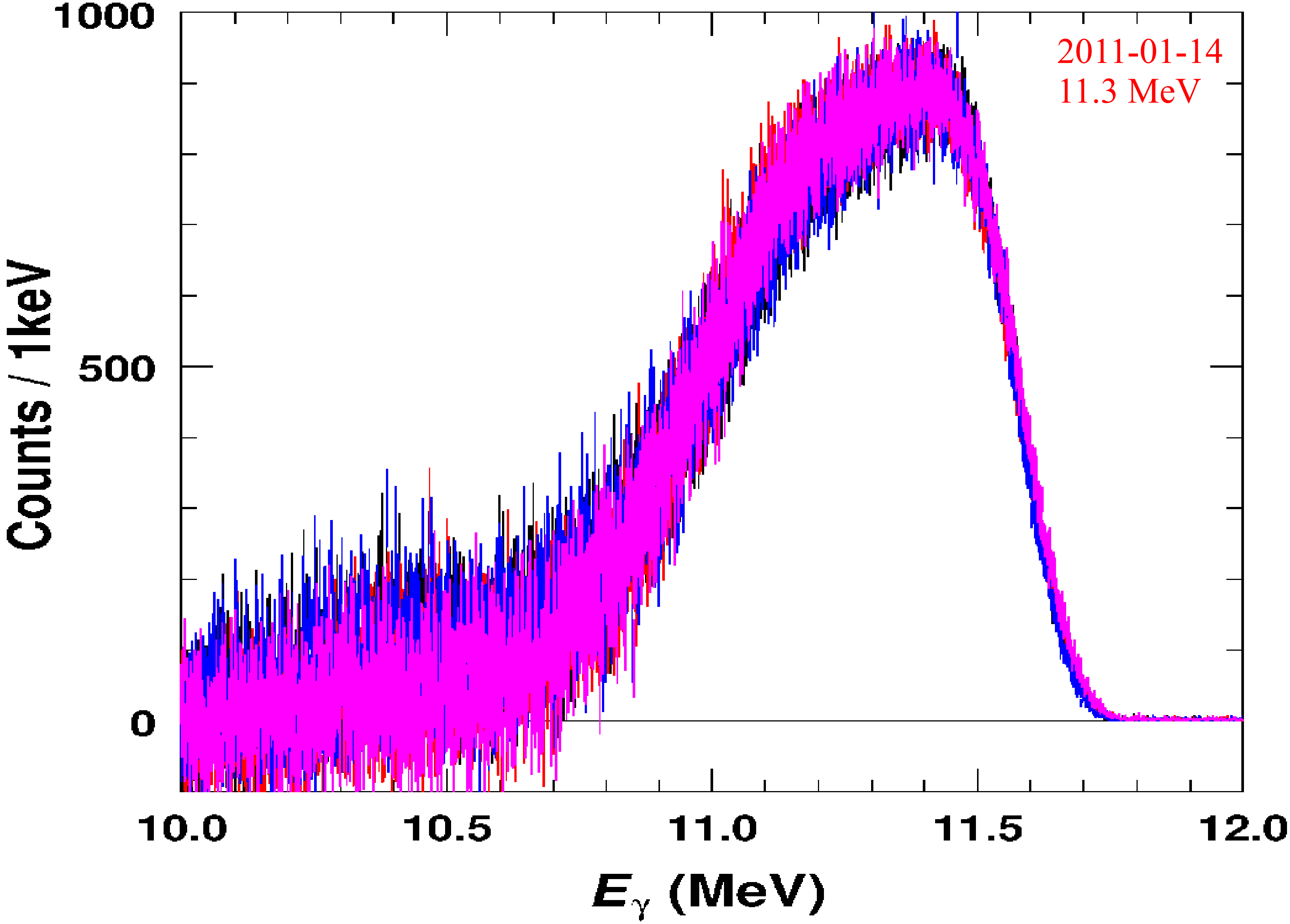
2011-01-14
11.3 MeV





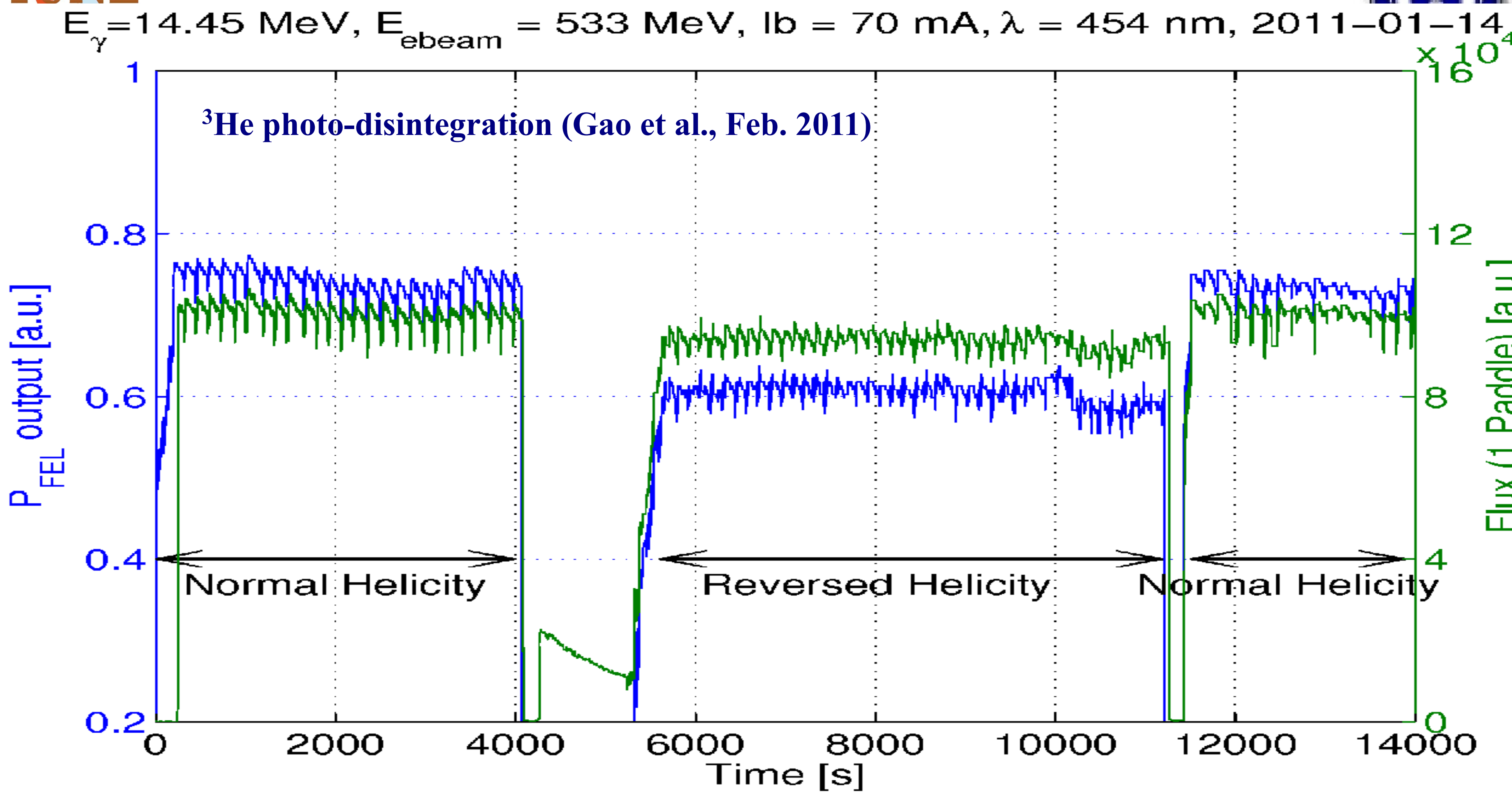
Gamma-ray beam imager: Part of Ph.D. thesis work of Changchun Sun (Duke, 2009)

Beam Aiming Consistency: Gamma-ray Spectra



Black (normal) ->Red(reversed) ->Blue (normal)->Magenta(reversed)

Helicity Switch Using OK-5 FEL



Slow Switch: 5 – 15 minutes

Goal

Fast Switch:

few seconds or faster

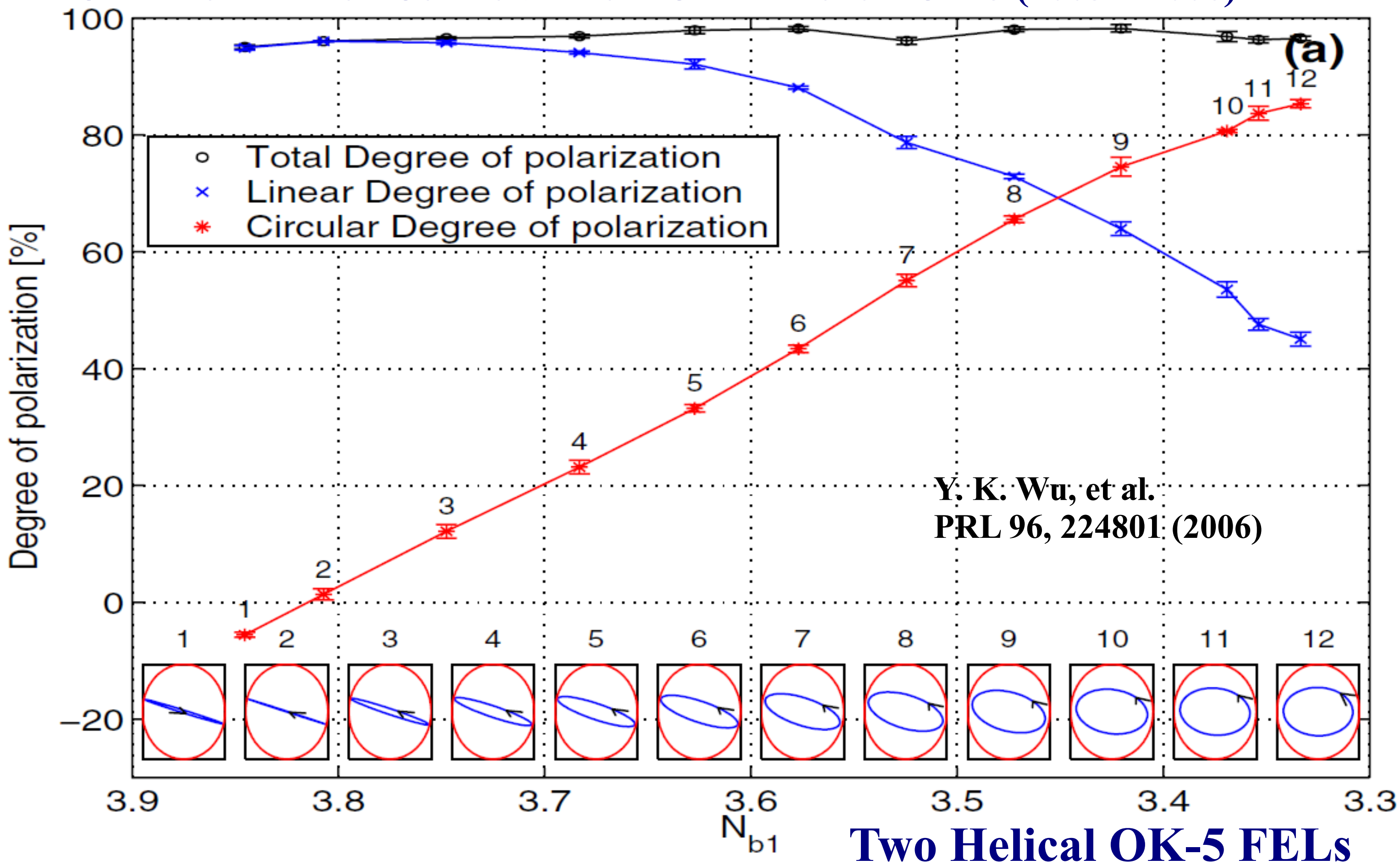
III. Controlling and Manipulating FEL Polarization States

- **Fast Helicity Switch**
- **Rotatable Linear Polarization using Helical Wigglers**

Cross-Planar Wigglers in a high-gain FEL

K.-J. Kim, NIM-A 445, 329 (2000).

DOK-1 Polarization Control: Linear OK4 + Helical OK-5 (2005 – 2006)



Two Helical OK-5 FELs

Goal

Linear Polarization FEL

HIGS/TUNL, Duke University, US

Facility/Project: HIGS

Institution: TUNL and Duke University

Country: US

Energy (MeV): 1 – 100

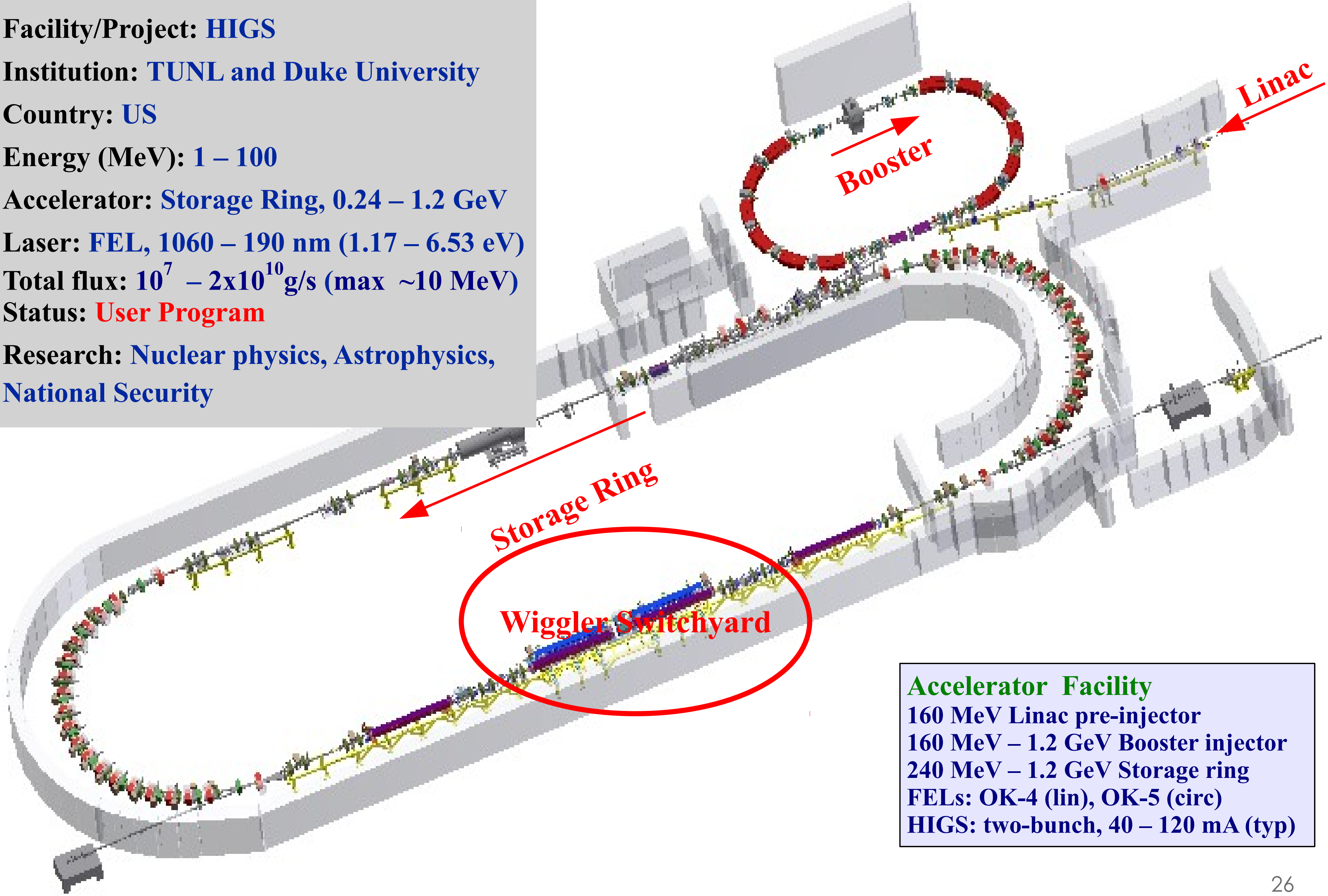
Accelerator: Storage Ring, 0.24 – 1.2 GeV

Laser: FEL, 1060 – 190 nm (1.17 – 6.53 eV)

Total flux: 10^{7} – $2\text{x}10^{10}$g/s (max ~10 MeV)

Status: User Program

Research: Nuclear physics, Astrophysics, National Security

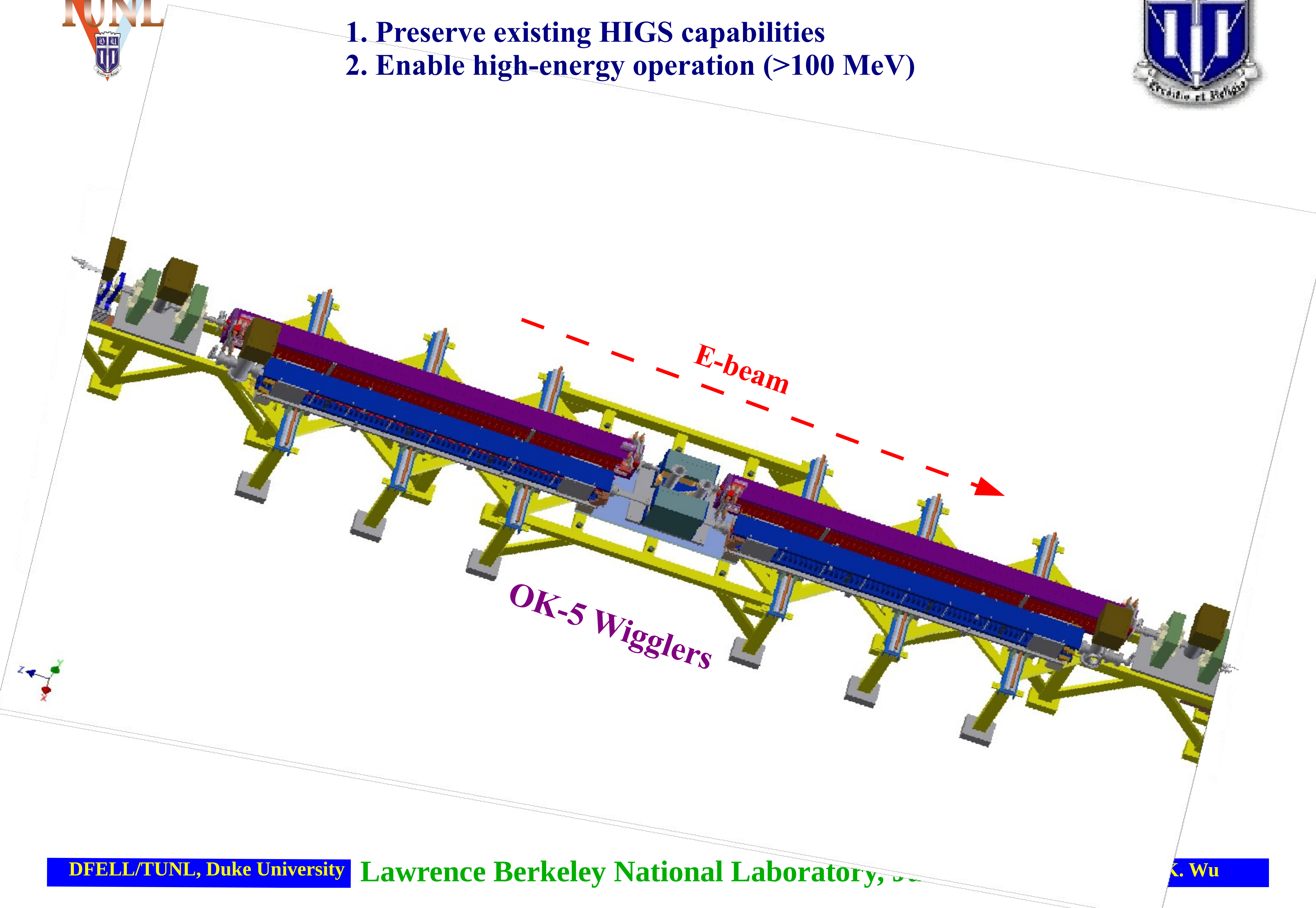


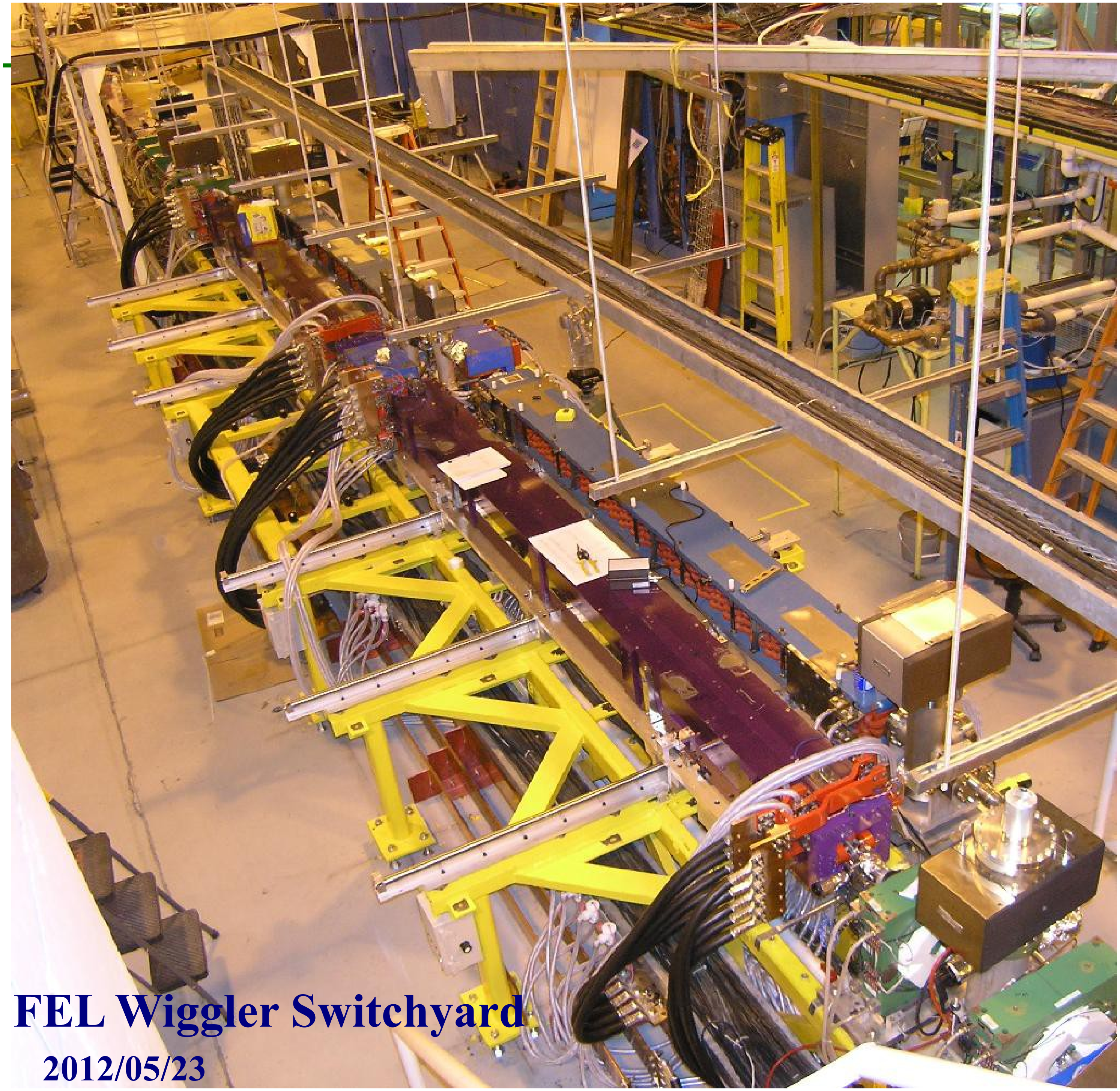
Accelerator Facility

160 MeV Linac pre-injector
160 MeV – 1.2 GeV Booster injector
240 MeV – 1.2 GeV Storage ring
FELs: OK-4 (lin), OK-5 (circ)
HIGS: two-bunch, 40 – 120 mA (typ)

Switchyard for OK-4 and OK-5 Wigglers

1. Preserve existing HIGS capabilities
2. Enable high-energy operation (>100 MeV)

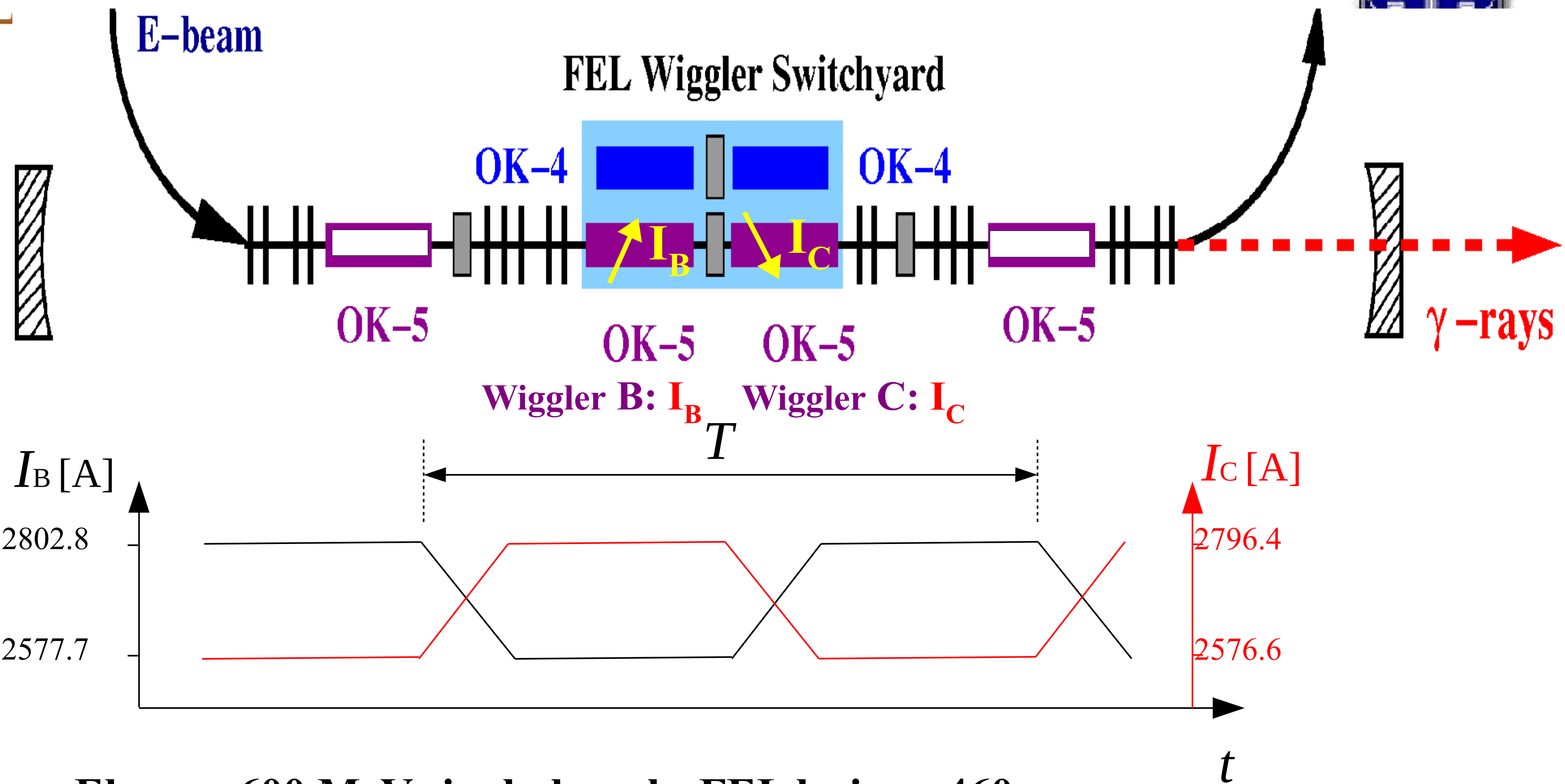




FEL Wiggler Switchyard

2012/05/23

Experimental Setup: Helicity Switch

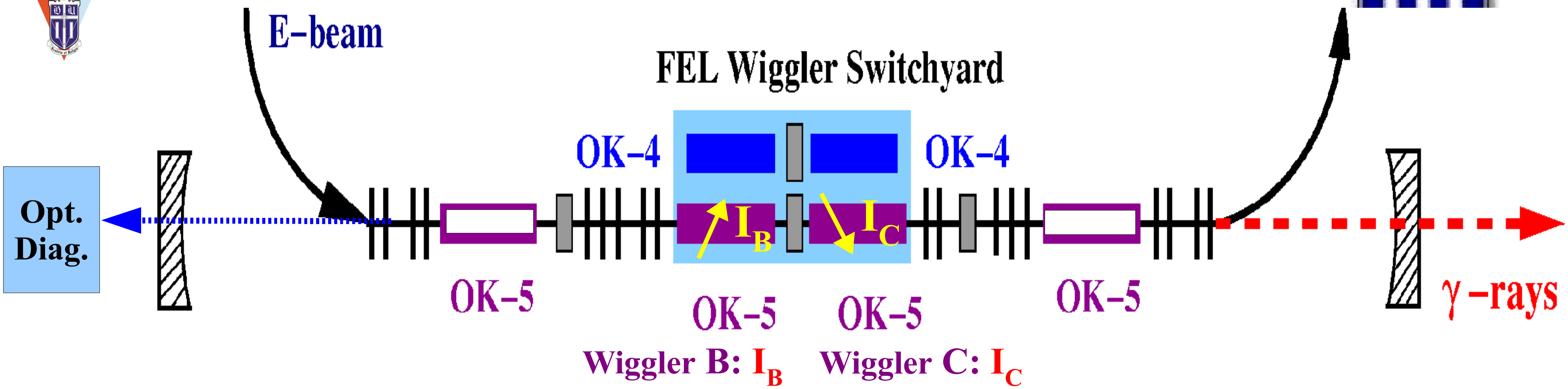


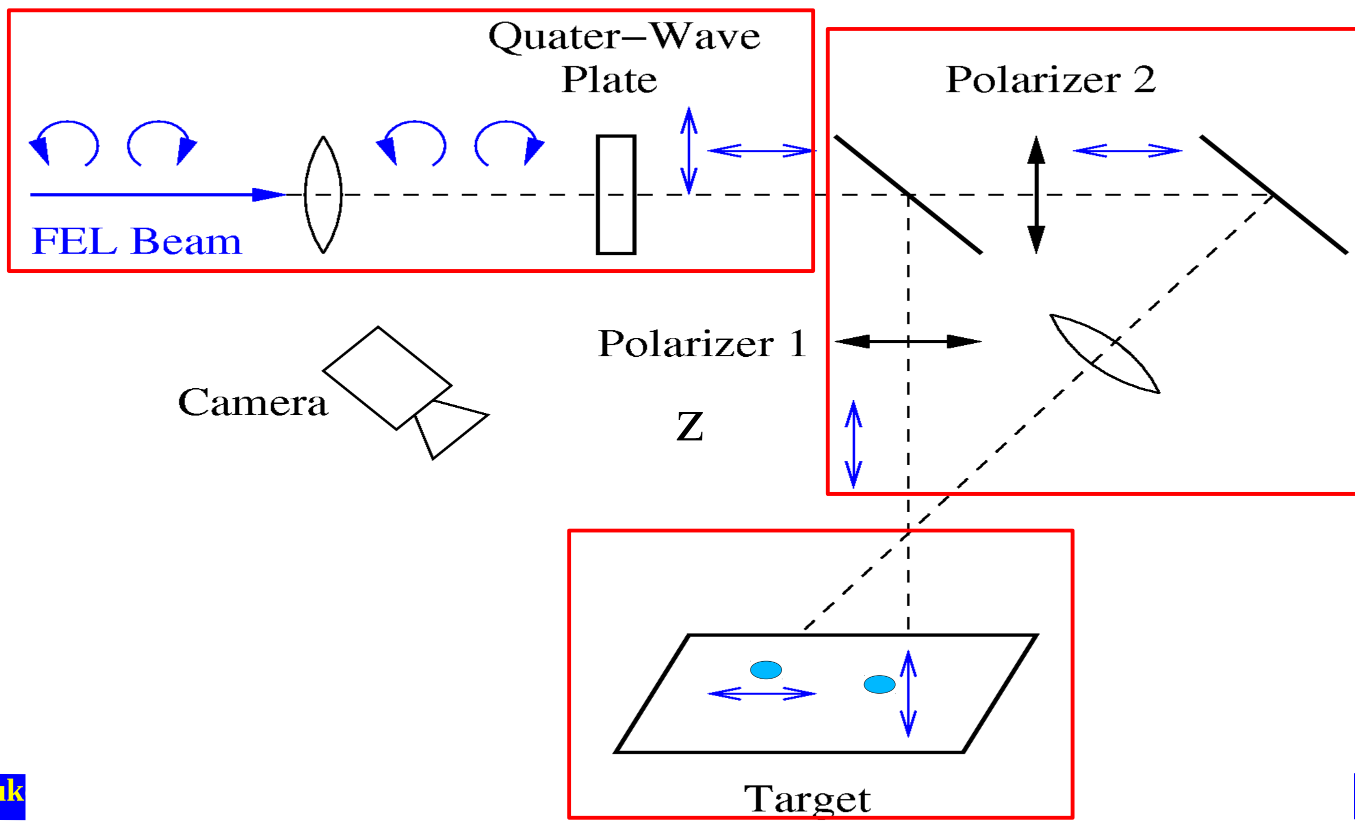
Ebeam: 600 MeV single-bunch; FEL lasing ~460 nm
I_B range: [2577.7, 2802.8] A; I_C range: [2576.6, 2796.4] A

Lattice Ramping/Switching

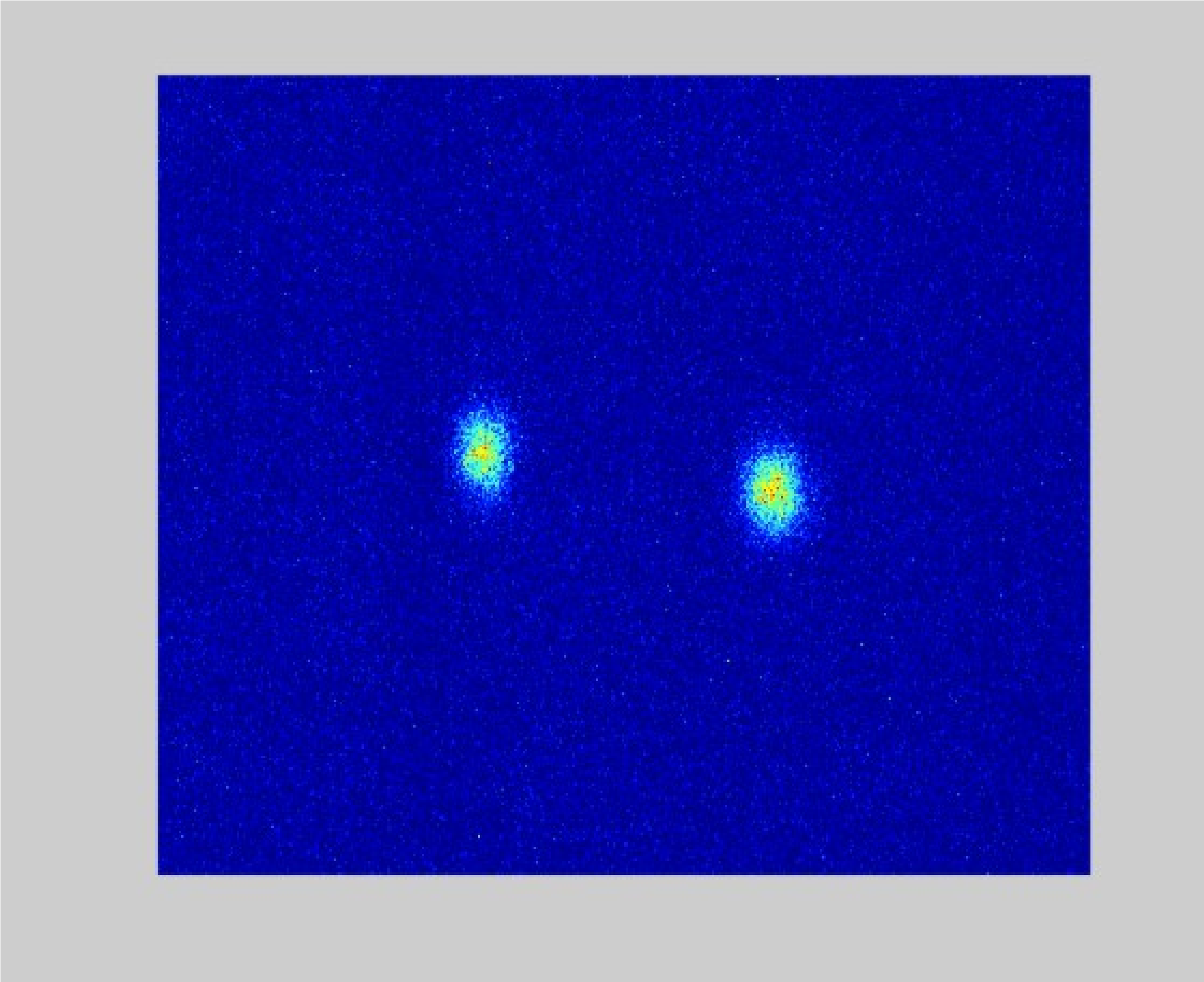
# of quads: 18, all the quads in FEL straight section
# of x-correctors: 56, all horizontal orbit feedback correctors
# of y-correctors: 24, all vertical orbit feedback correctors

Experimental Setup: Helicity Switch

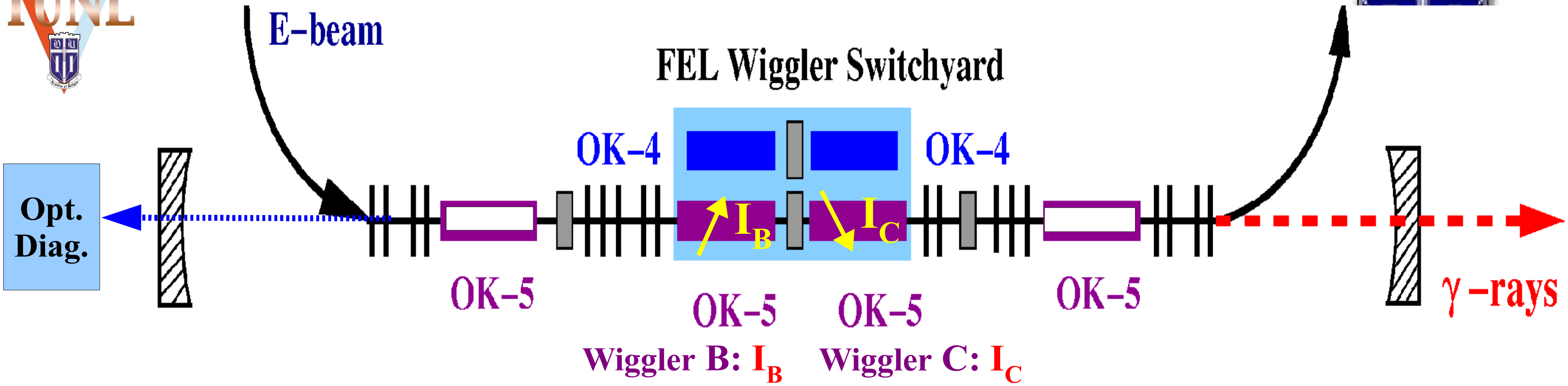


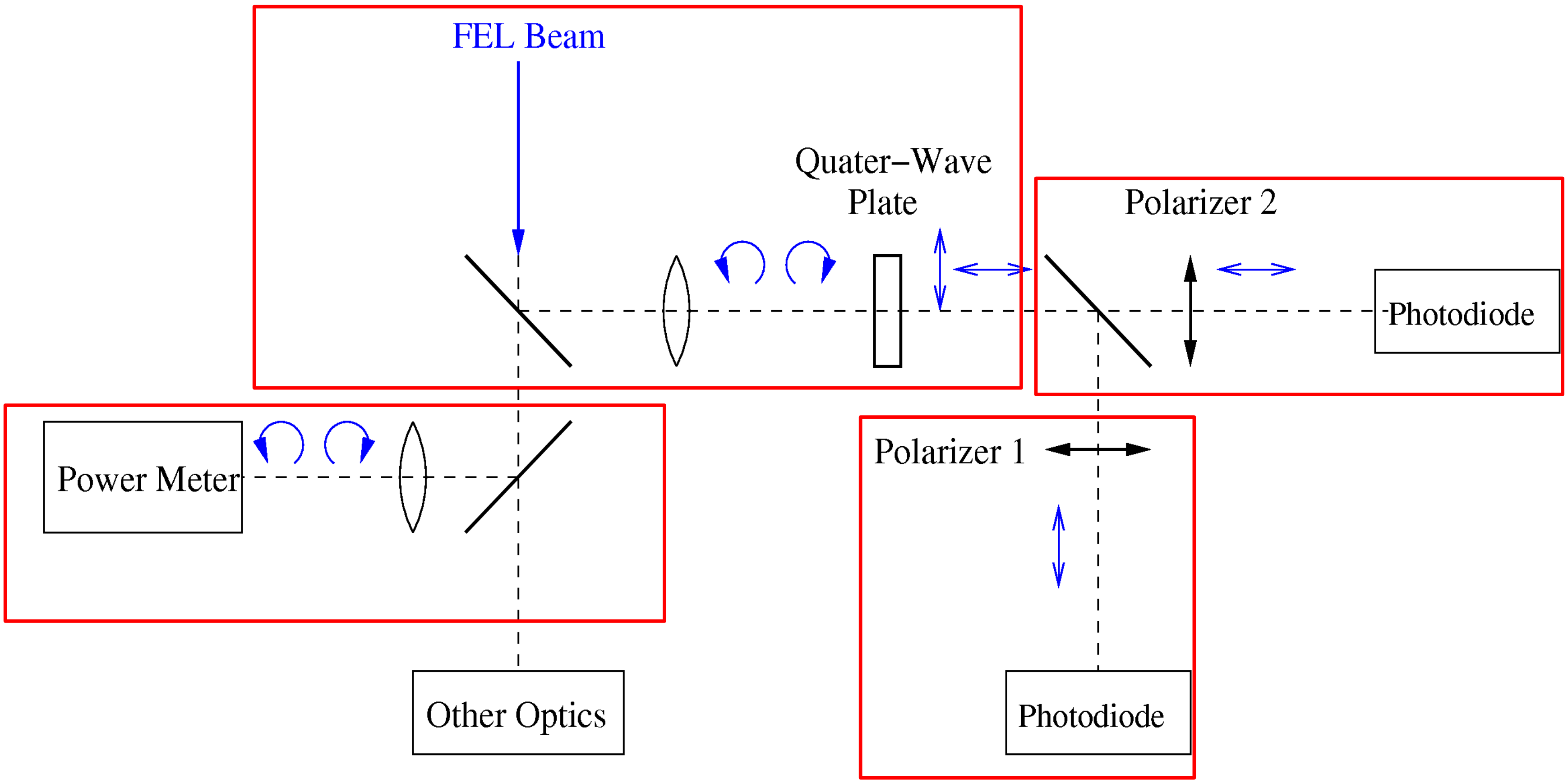


Helicity Switch (5 Hz)



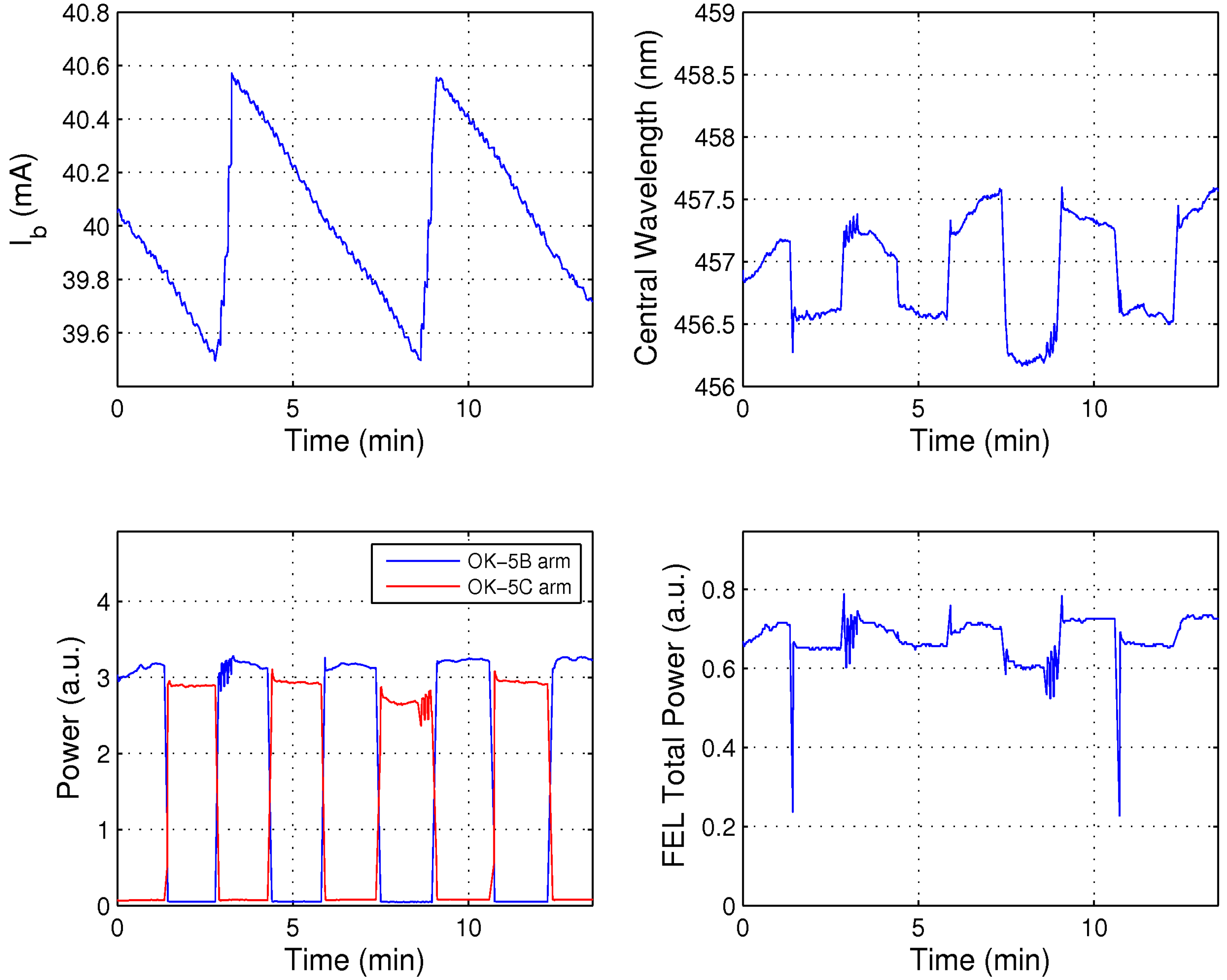
Experimental Setup: Helicity Switch



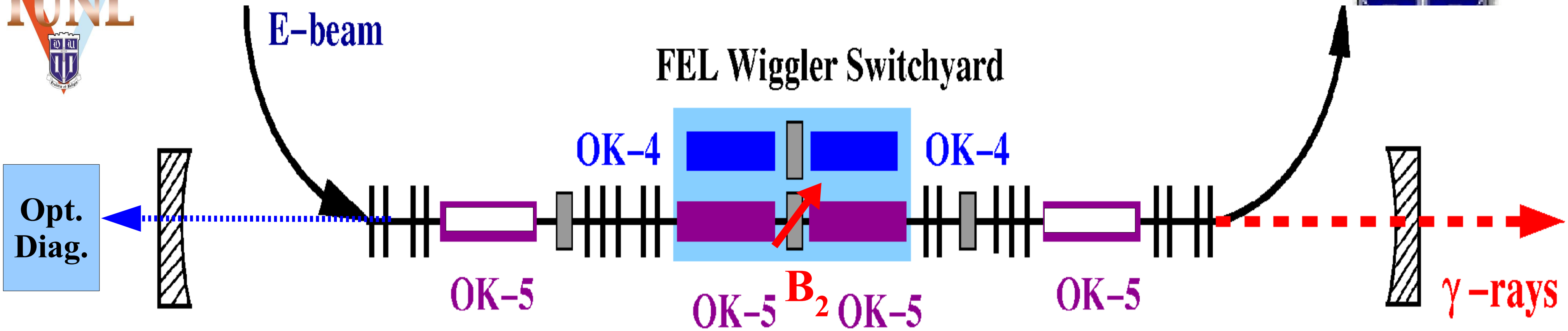


Helicity Switch: Power Measurements (*Preliminary Results*)

40 mA, Suppressed Coherent Radiation



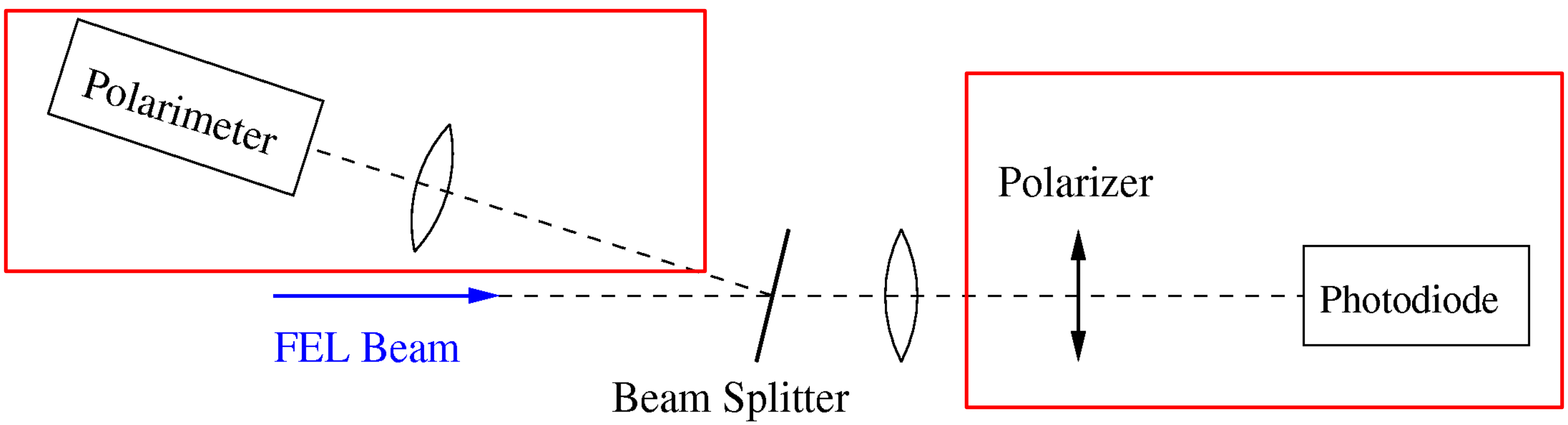
Experimental Setup: Rotatable Linear Polarization



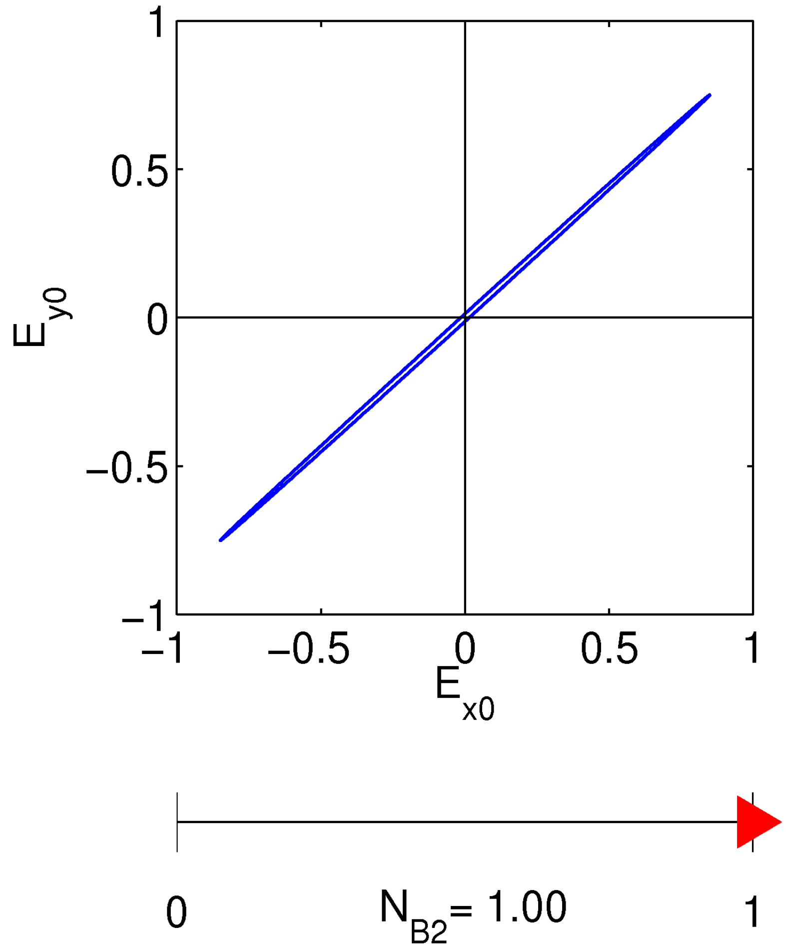
OK5B:
Normal Pol.

OK5C:
Reversed Pol.

Thorlabs: PA530



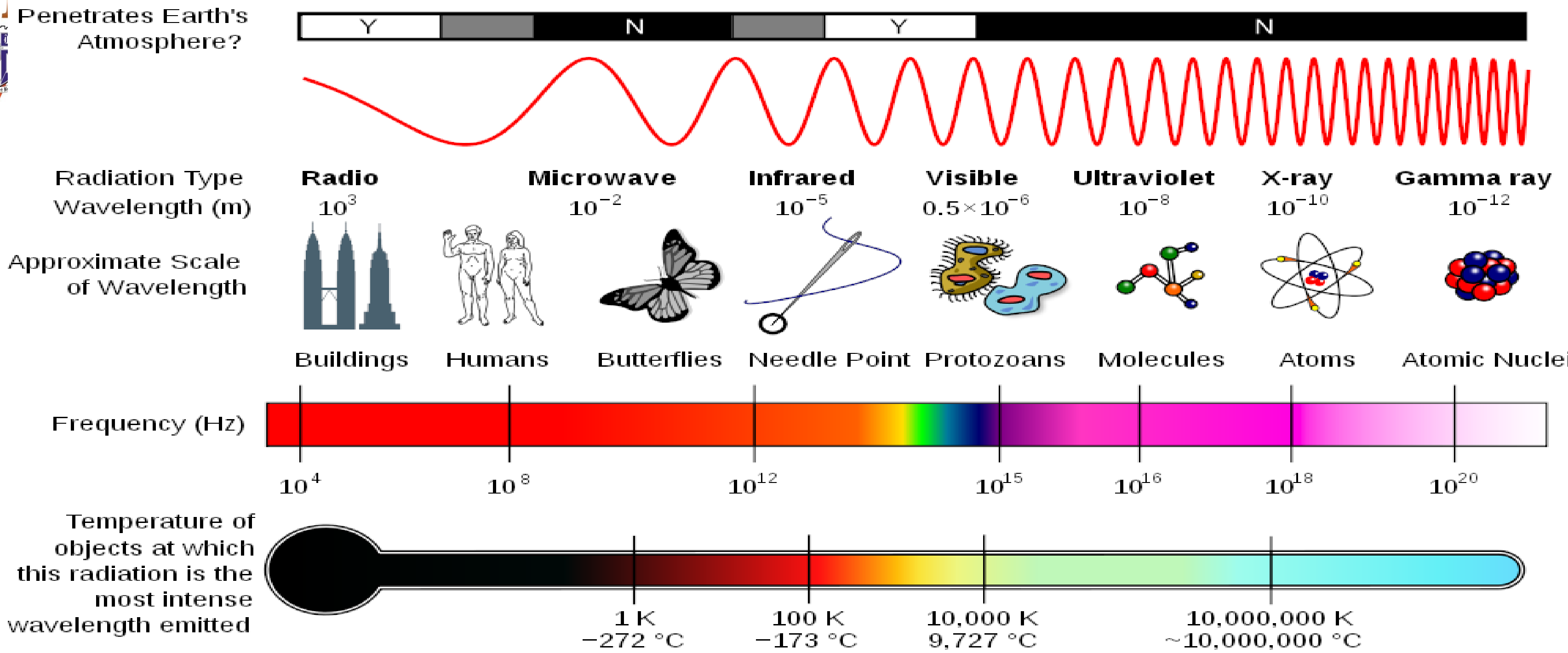
Rotating Linear Polarization, with Polarimeter

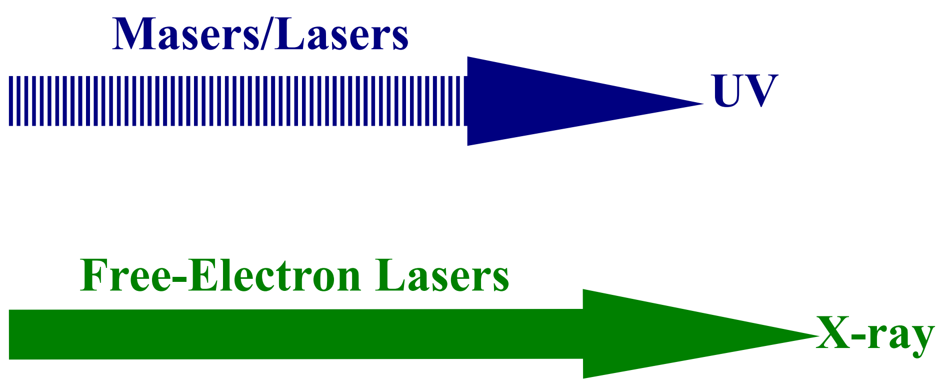


IV. Exploring and Exploiting Polarization Control of FELs

- **FEL's Outstanding Advantages over Conventional Lasers**

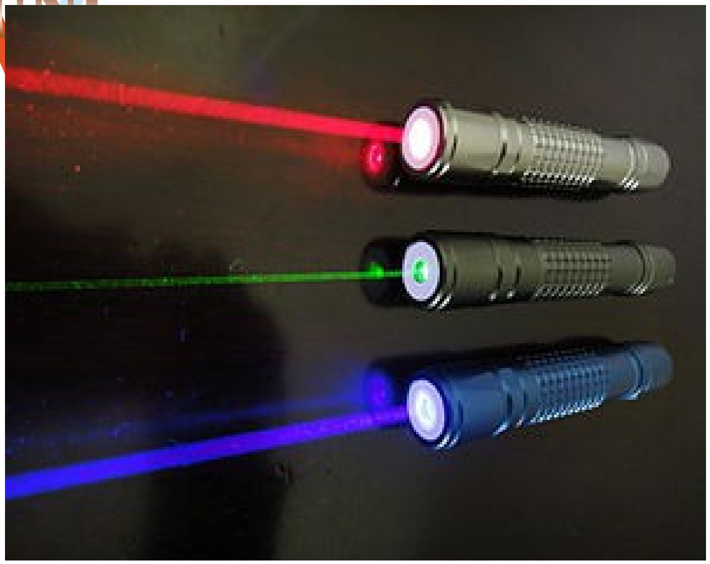
Photon Energy: Wide Range and Tuneability



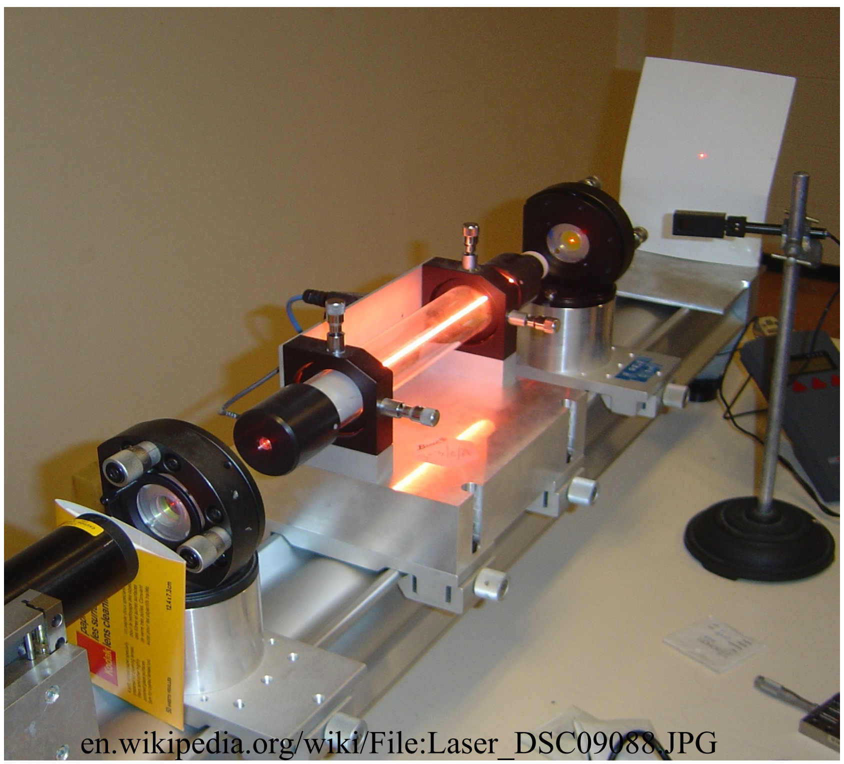


http://en.wikipedia.org/wiki/Electromagnetic_spectrum

Limitations of Conventional Lasers



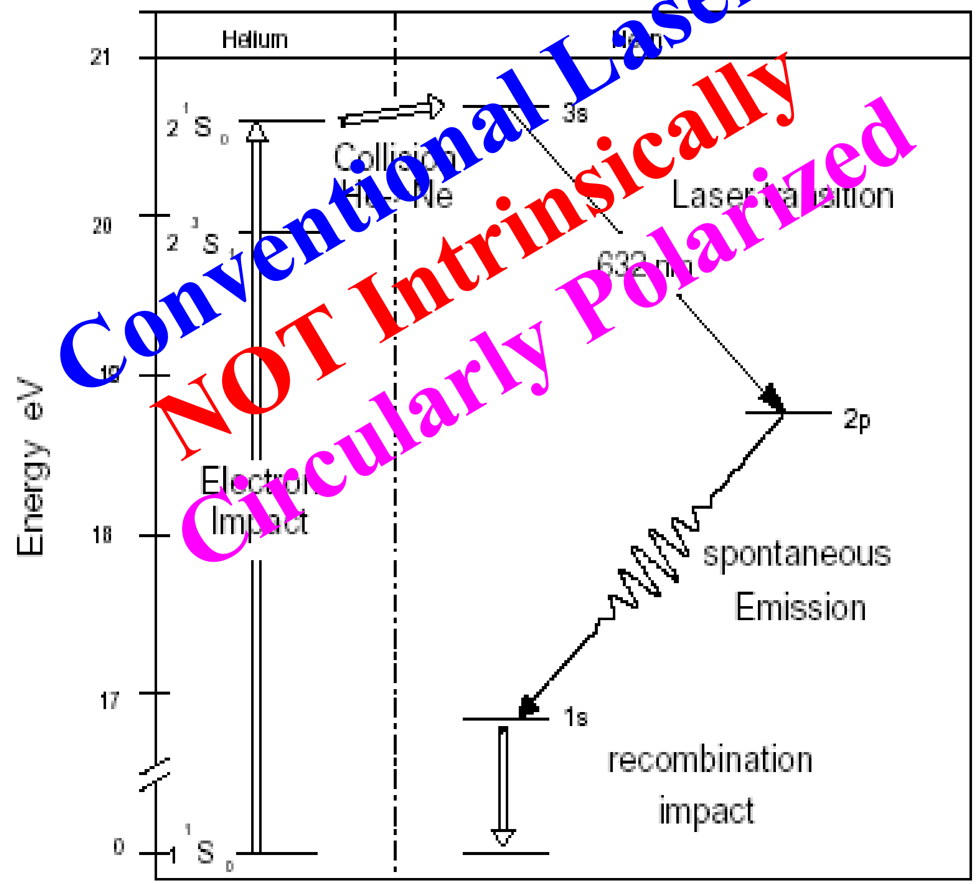
http://en.wikipedia.org/wiki/Laser_pointer



en.wikipedia.org/wiki/File:Laser_DSC09088.JPG

Laser Medium (Gain Medium)

- Gases
- Liquids
- Solids



Conventional Lasers
NOT Intrinsically
Circularly Polarized

http://electron6.phys.utk.edu/optics421/modules/m5a/laser_systems.htm

Outstanding Advantages of FELs

E_{ph}

Wavelength Advantage

- Broad-range of wavelength operation: microwave to x-ray
- Tunability

+

New Research Opportunities

Polarization Advantage

- Pure circular polarization
- Helicity switch and rotatable linear polarization

Pol

Thank You!