A Two-Color Storage Ring FEL

Jun Yan

Triangle Universities Nuclear Laboratory, and

Department of Physics, Duke University

Aug. 26, 2015

Collaborators:

Y.K. Wu, H. Hao, J.Y. Li, S. Mikhailov, V. Popov and

N. Vinokurov (BINP), S. Huang (Peking Univ.), J. Wu (SLAC)

Work supported by **U.S. Grant: DE-FG02-97ER41033**

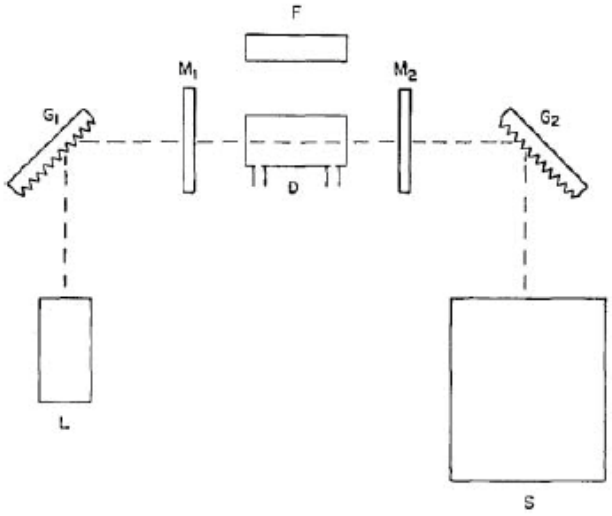
Outline

- Introduction
  - Multi-color lasing with conventional lasers and FELs
  - Duke Storage Ring FEL: Configurations with Multiple Undulators
- Two-color FEL operation at Duke
  - Undulator Configuration and Dual-band high-reflectivity FEL mirrors
  - Wavelength tuning
  - Power control
- Two-color Gamma-ray production at HIGS

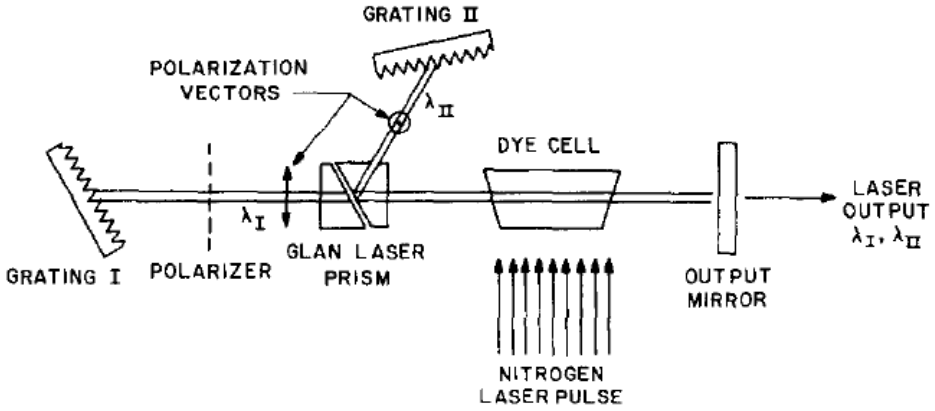
I. Introduction:

- **Multi-color lasing with conventional lasers and FELs**

Multi-color lasing with conventional lasers



E. Zalewski and R. Keller,
Appl. Optics 10, 2773 (1971).



H. Pilloff, Appl. Phys. Lett. 21, 339 (1972).

Gain medium:

Dye;

Ti:sapphire;

Diode;

Fiber…

Applications:

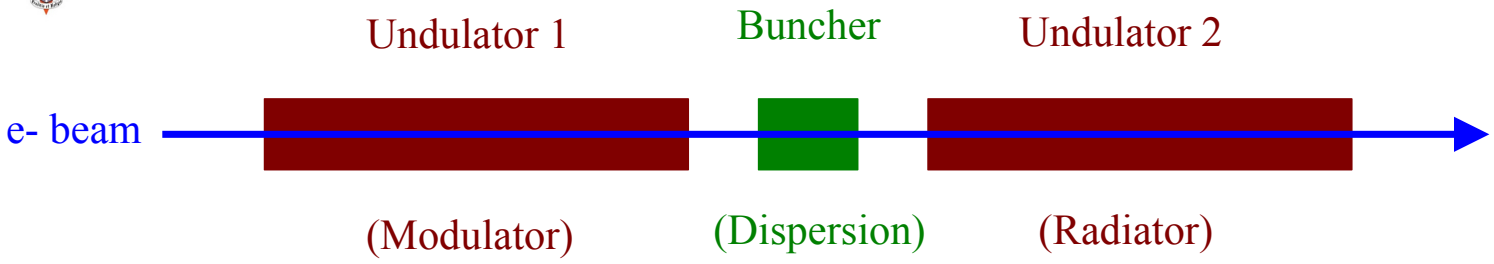
Pump-probe;

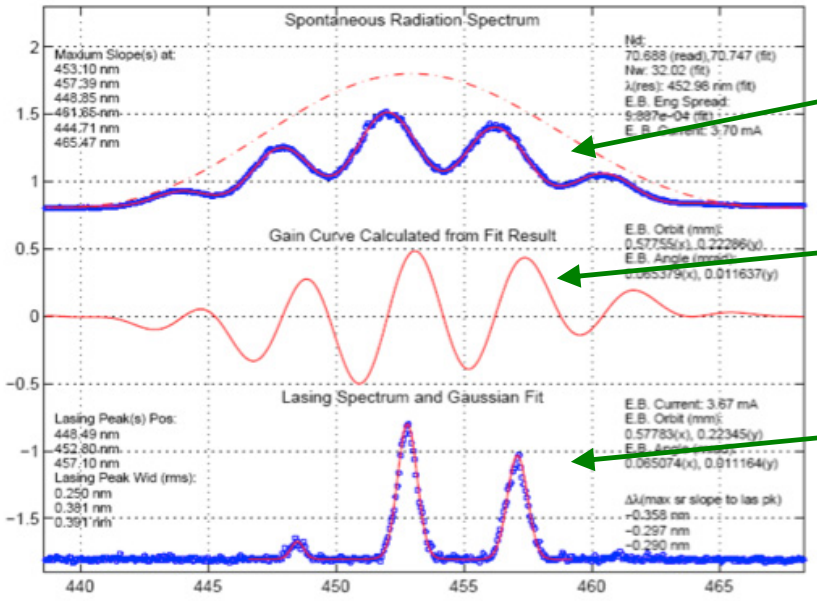
Wavelength-division multiplexing;

Photomixing for terahertz radiation generation;

…

Multi-color lasing using Optical Klystron (OK) FEL





Spontaneous Radiation Spectrum

Calculated Gain Curve

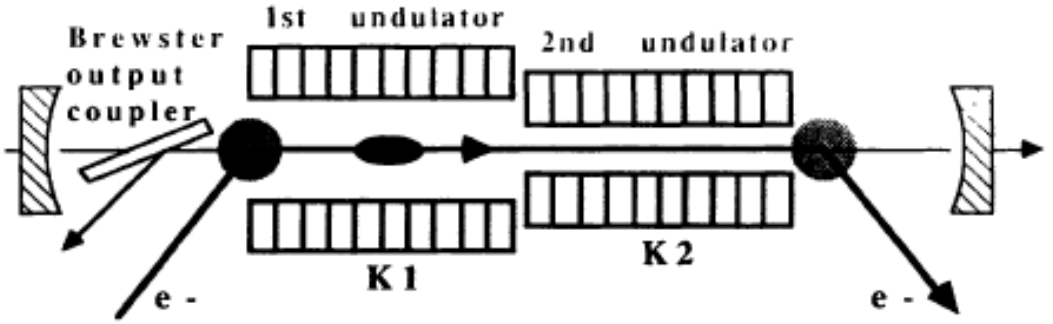
FEL Spectrum

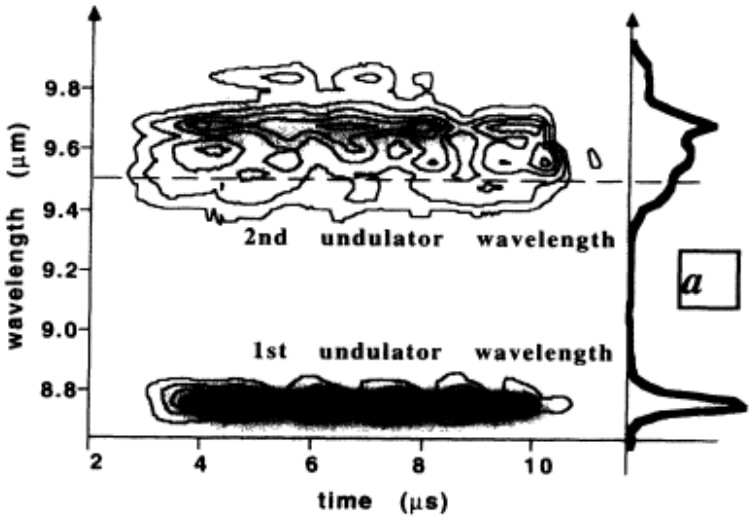
I.B. Drobyazko, G.N. Kulipanov, V.N. Litvinenko, I.V. Pinayev, V.M. Popik, I.G. Silvestrov, and A.N. Skrinsky et al., Nucl. Instr. Meth. A 282, 424 (1989).

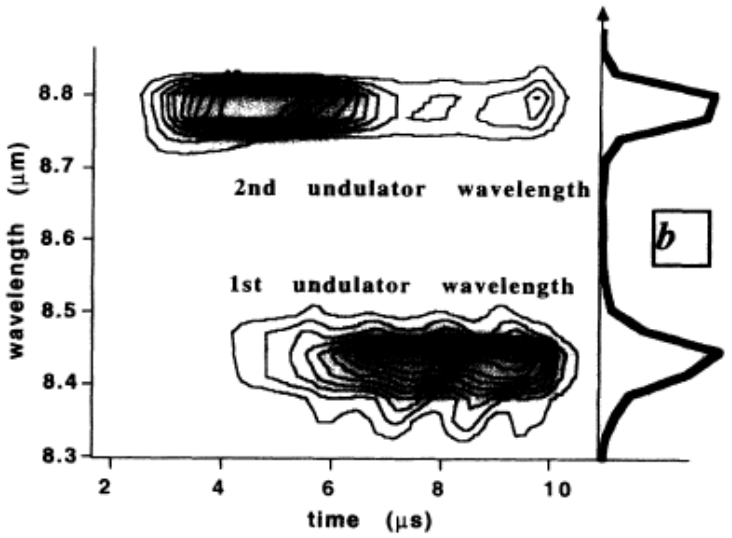
S. Huang, "Experimental Research on Storage Ring Free-Electron Laser," Ph.D. dissertation (2009).

CLIO FEL (Oscillator FEL, mid-infrared)

$$\lambda_{FEL} = \lambda_u \frac{1 + K^2/2}{2\gamma^2}$$

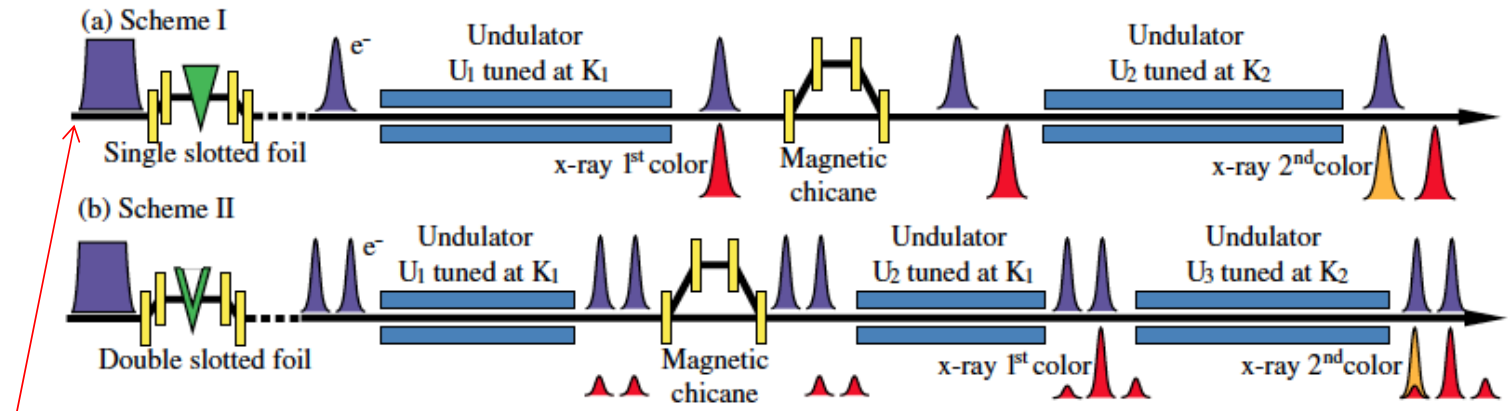


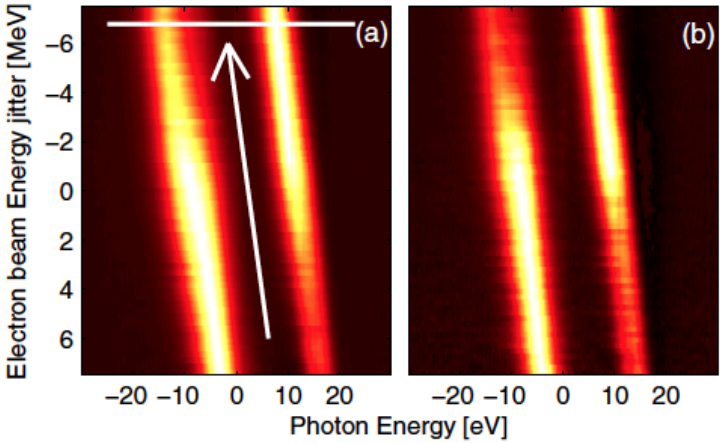


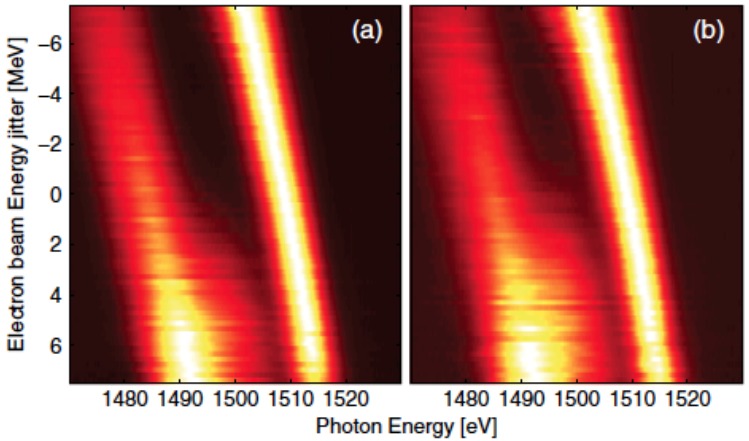


D.A. Jaroszynski, R. Prazeres, F. Glotin, and J.M. Ortega, Phys. Rev. Lett. 72, 2387 (1994).

LCLS, SLAC (SASE, soft x-ray, ~ 1.5 keV)

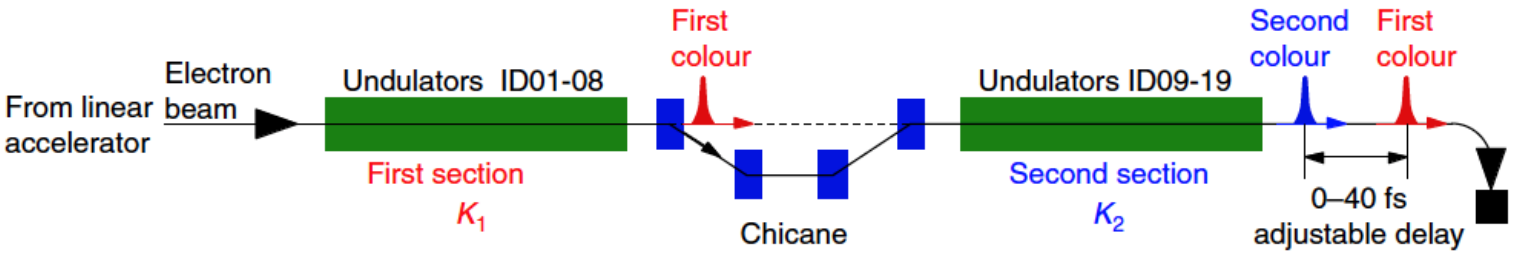


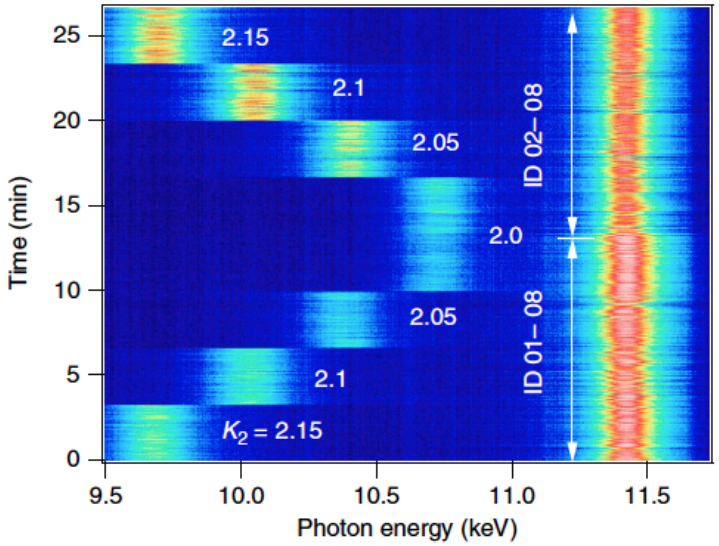


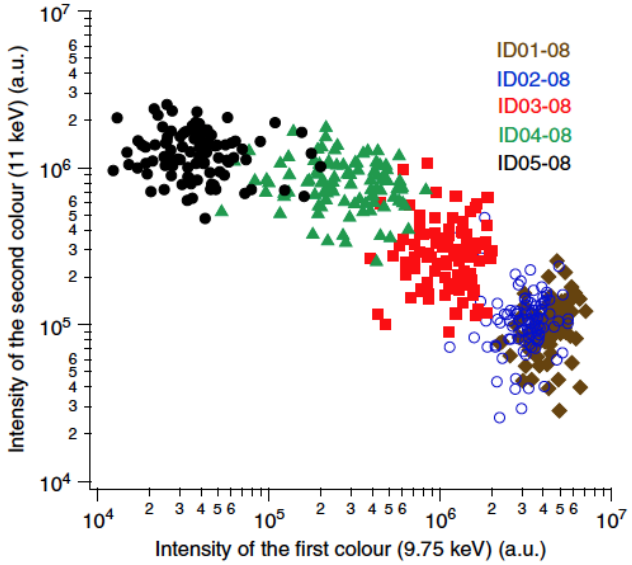


A.A. Lutman, R. Coffee, Y. Ding, Z. Huang, J. Krzywinski, T. Maxwell, and M. Messerschmidt et al., Phys. Rev. Lett. 110, 134801 (2013).

SACLA, Spring-8 (SASE, hard x-ray, ~ 10 keV)

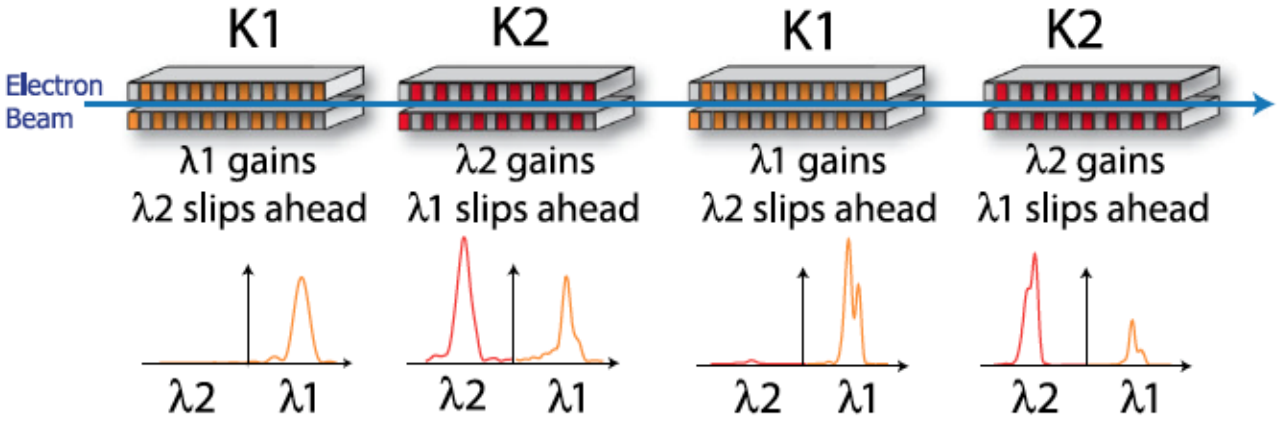


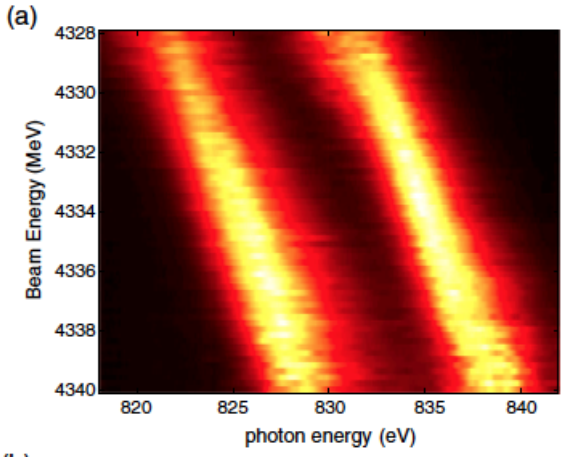


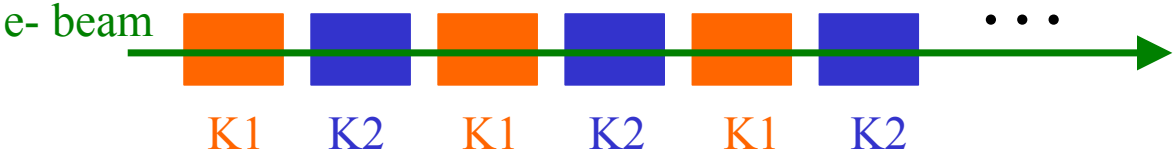


T. Hara, Y. Inubushi, T. Katayama, T. Sato, H. Tanaka, T. Tanaka, and T. Togashi et al., Nat. Commun. **4**, 2919 (2013).

LCLS, SLAC (SASE, soft x-ray, ~ 835 eV)

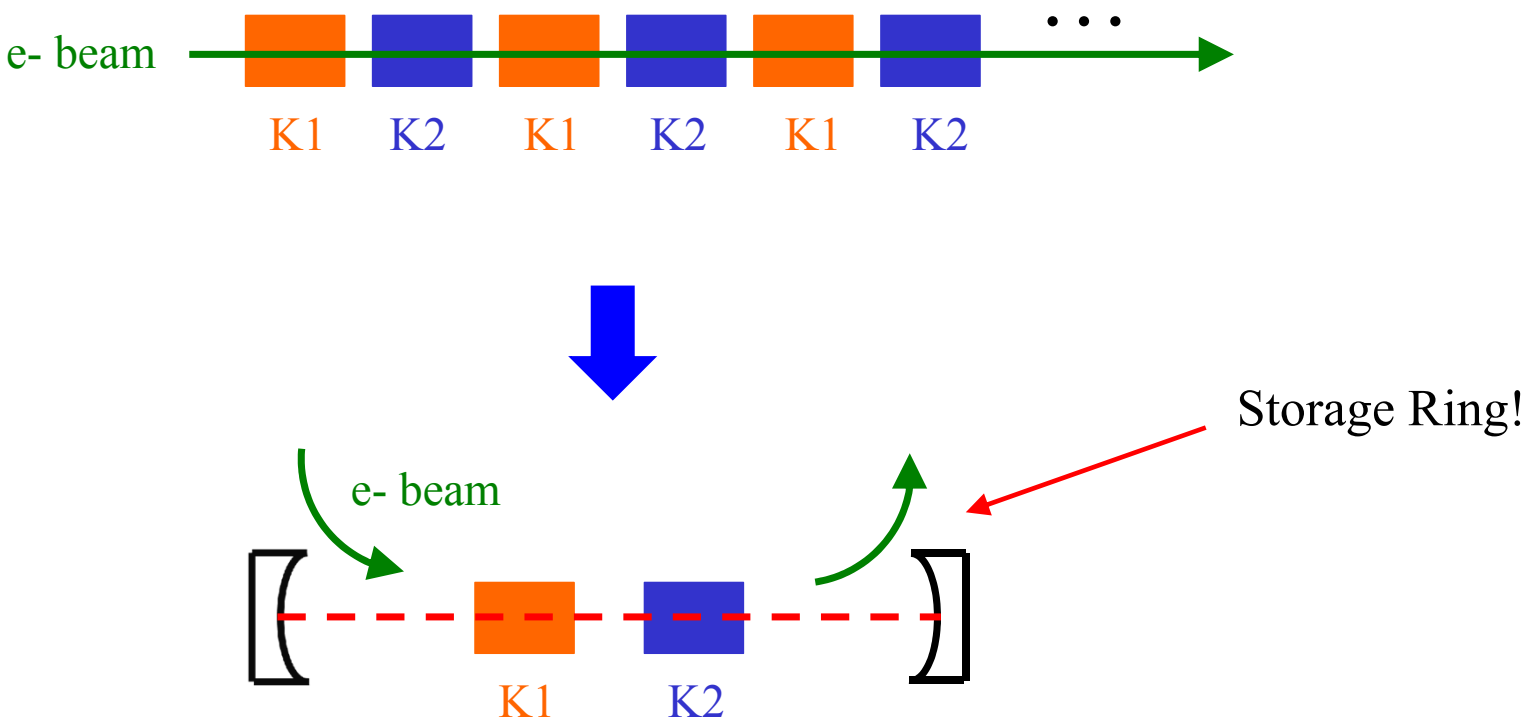






A. Marinelli, A.A. Lutman, J. Wu, Y. Ding, J. Krzywinski, H.-D. Nuhn, and Y. Feng et al., Phys. Rev. Lett. 111, 134801 (2013).

Two-color Storage Ring FEL?

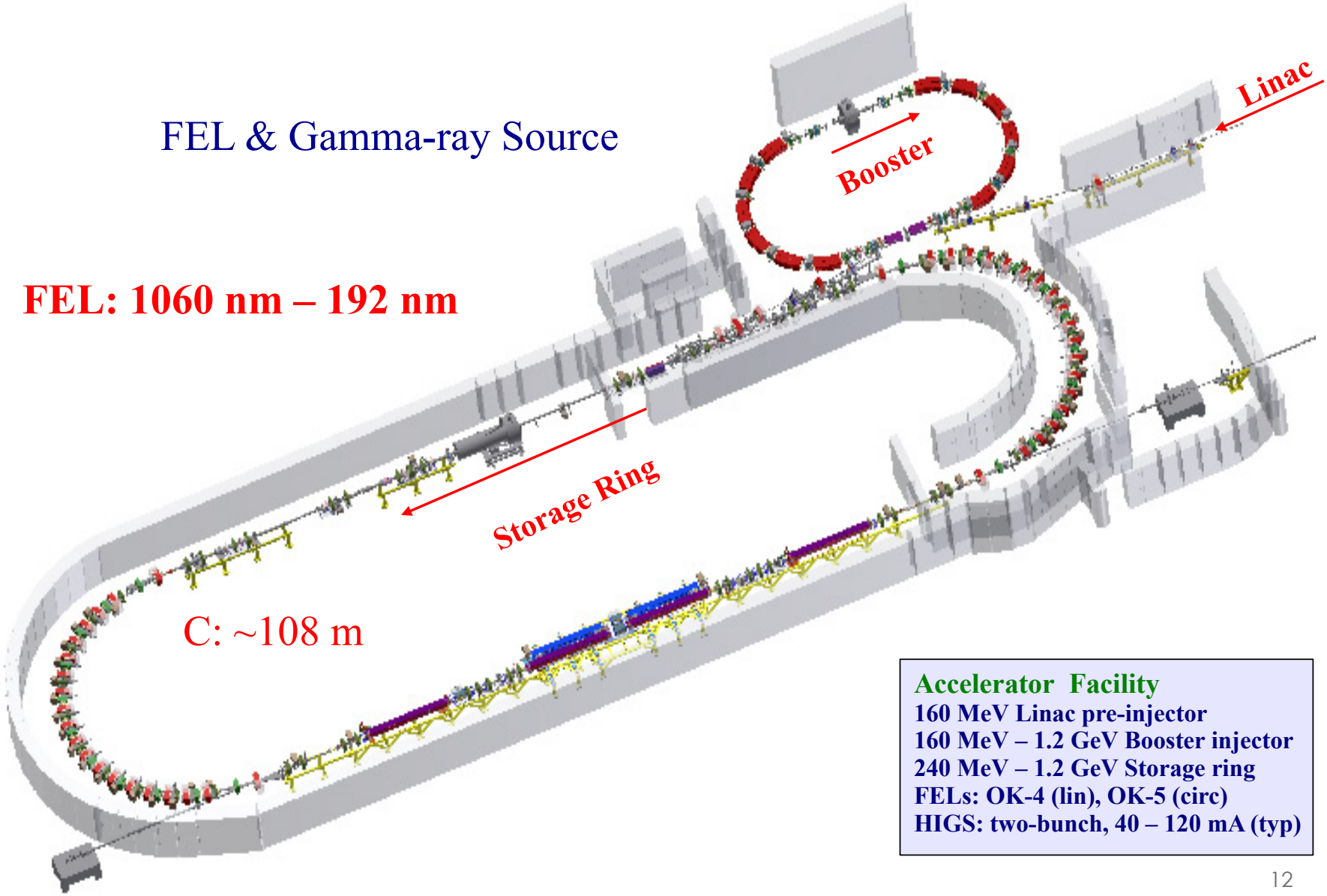


II. Duke Storage Ring FEL: Configurations with Multiple Undulators

A Wide Wavelength Range: Duke Storage Ring FEL

FEL & Gamma-ray Source

FEL: 1060 nm – 192 nm



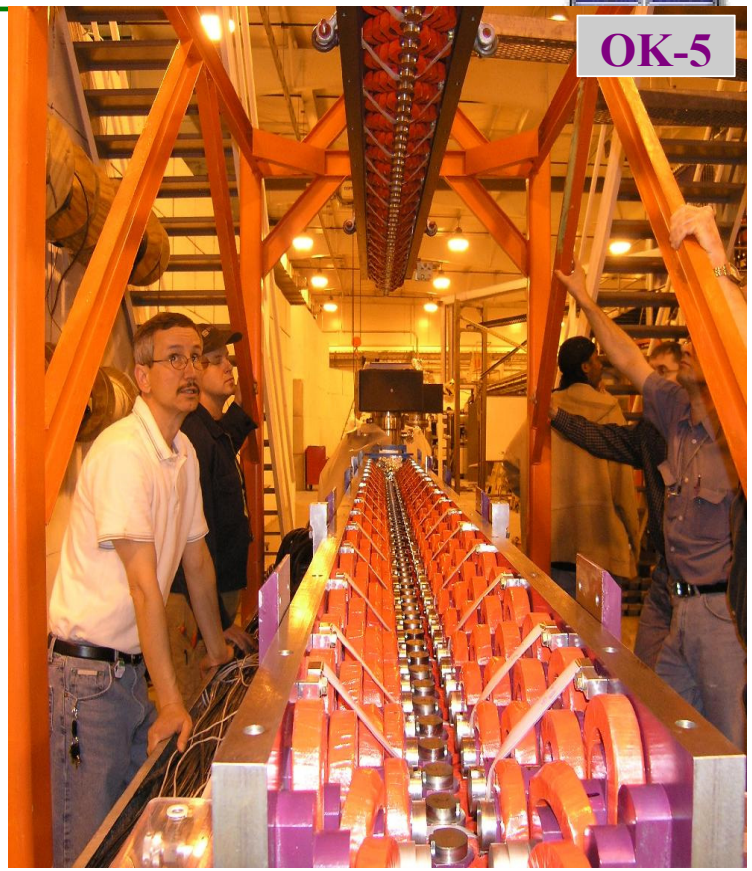
Accelerator Facility
160 MeV Linac pre-injector
160 MeV – 1.2 GeV Booster injector
240 MeV – 1.2 GeV Storage ring
FELs: OK-4 (lin), OK-5 (circ)
HIGS: two-bunch, 40 – 120 mA (typ)

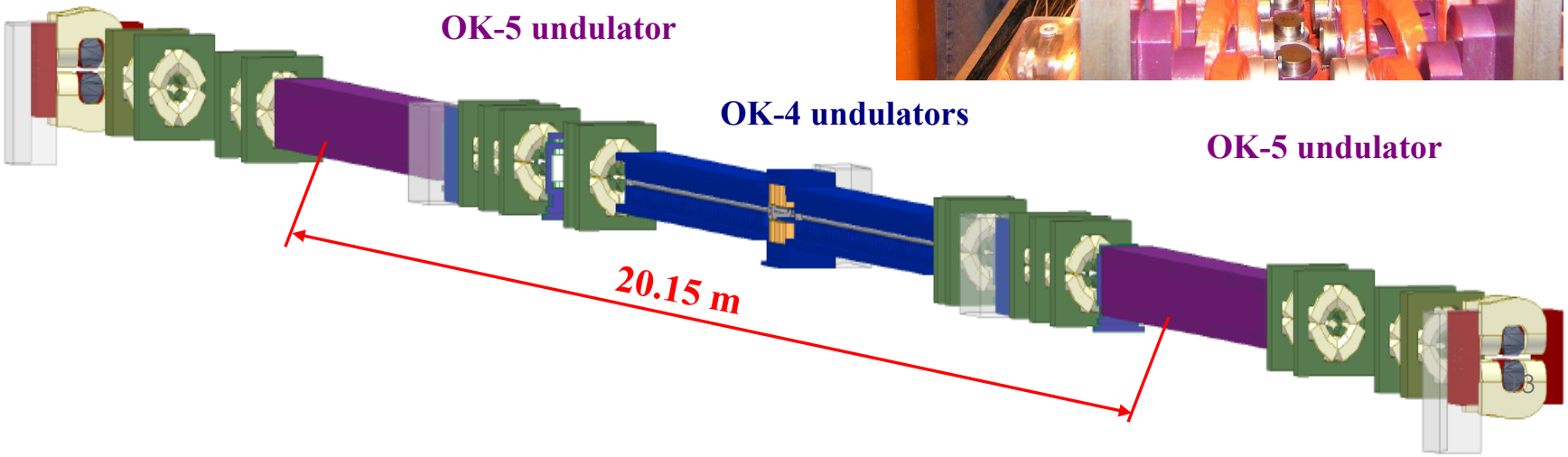
FELs with Planar and Helical Undulators: OK-4 and OK-5

Electromagnetic Undulators

- OK-4 : Planar undulators
- OK-5: Helical undulators

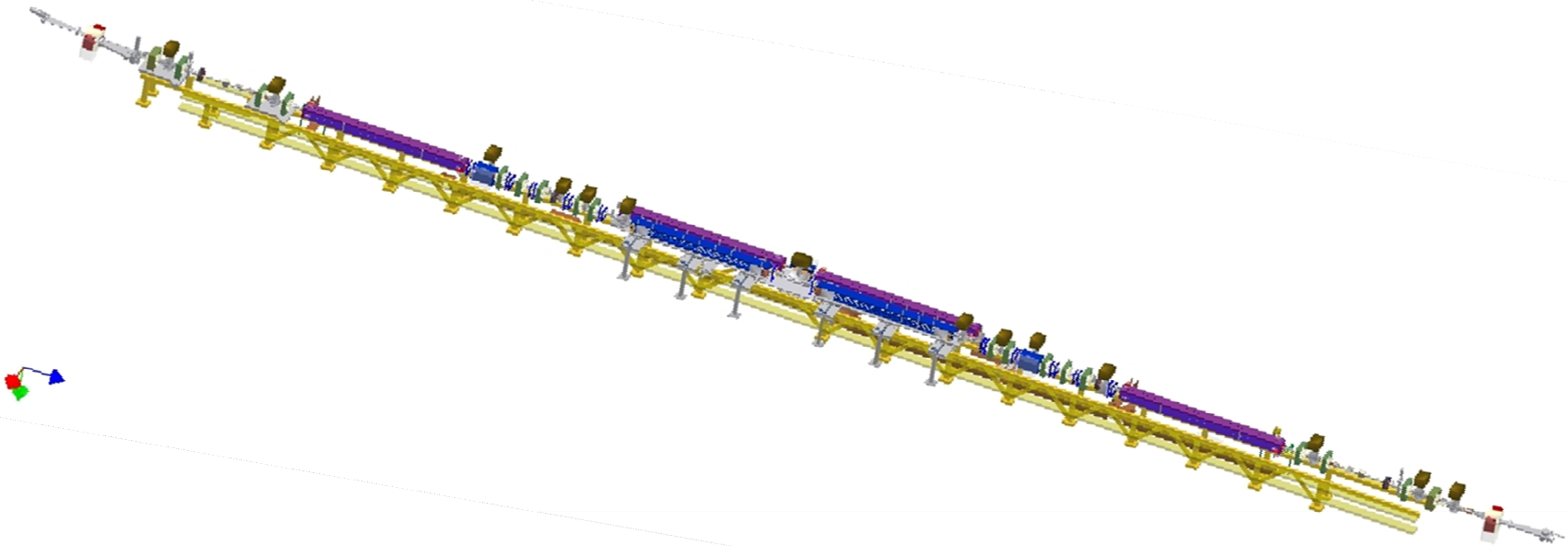
	OK-4	OK-5
Polarization	Linear	Circular
No. of reg. period	33	30
Undulator period (cm)	10	12
Peak field (kG) at 3kA	5.36	2.86





Switchyard for OK-4 and OK-5 Wigglers

Undulator Switchyard Upgrade



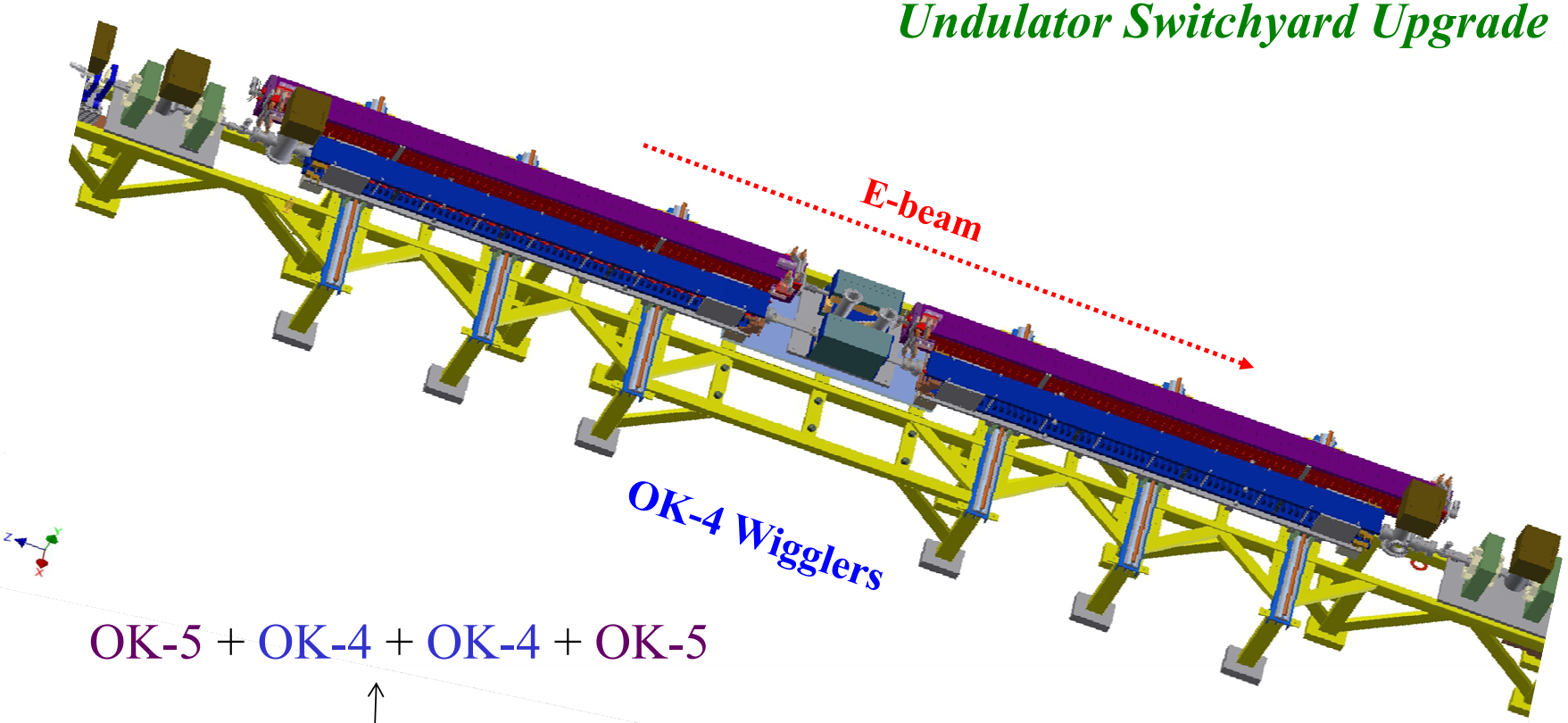
OK-5 + OK-4 + OK-4 + OK-5

↕

4 * OK-5

Switchyard for OK-4 and OK-5 Wigglers

Undulator Switchyard Upgrade



OK-5 + OK-4 + OK-4 + OK-5

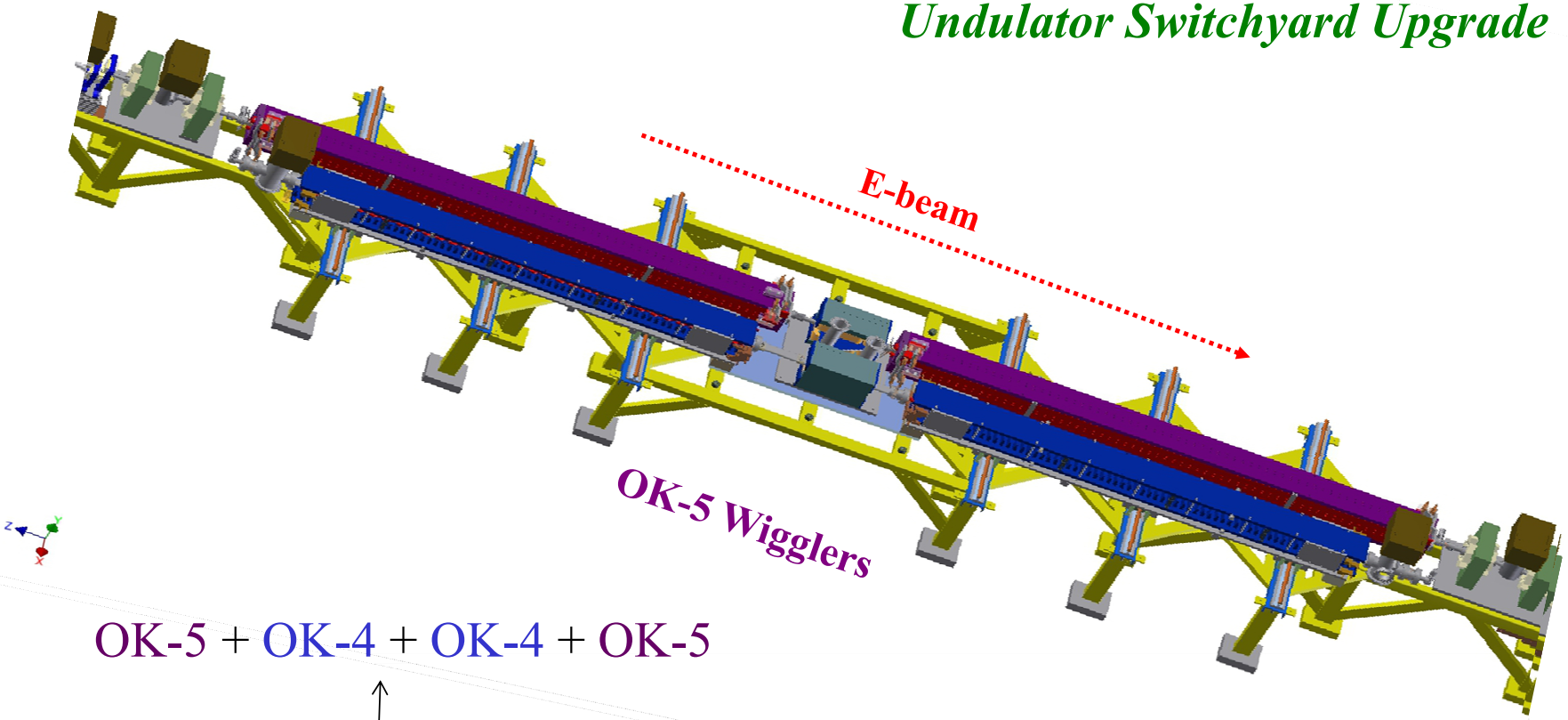
↕

4 * OK-5

Switchyard for OK-4 and OK-5 Wigglers

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

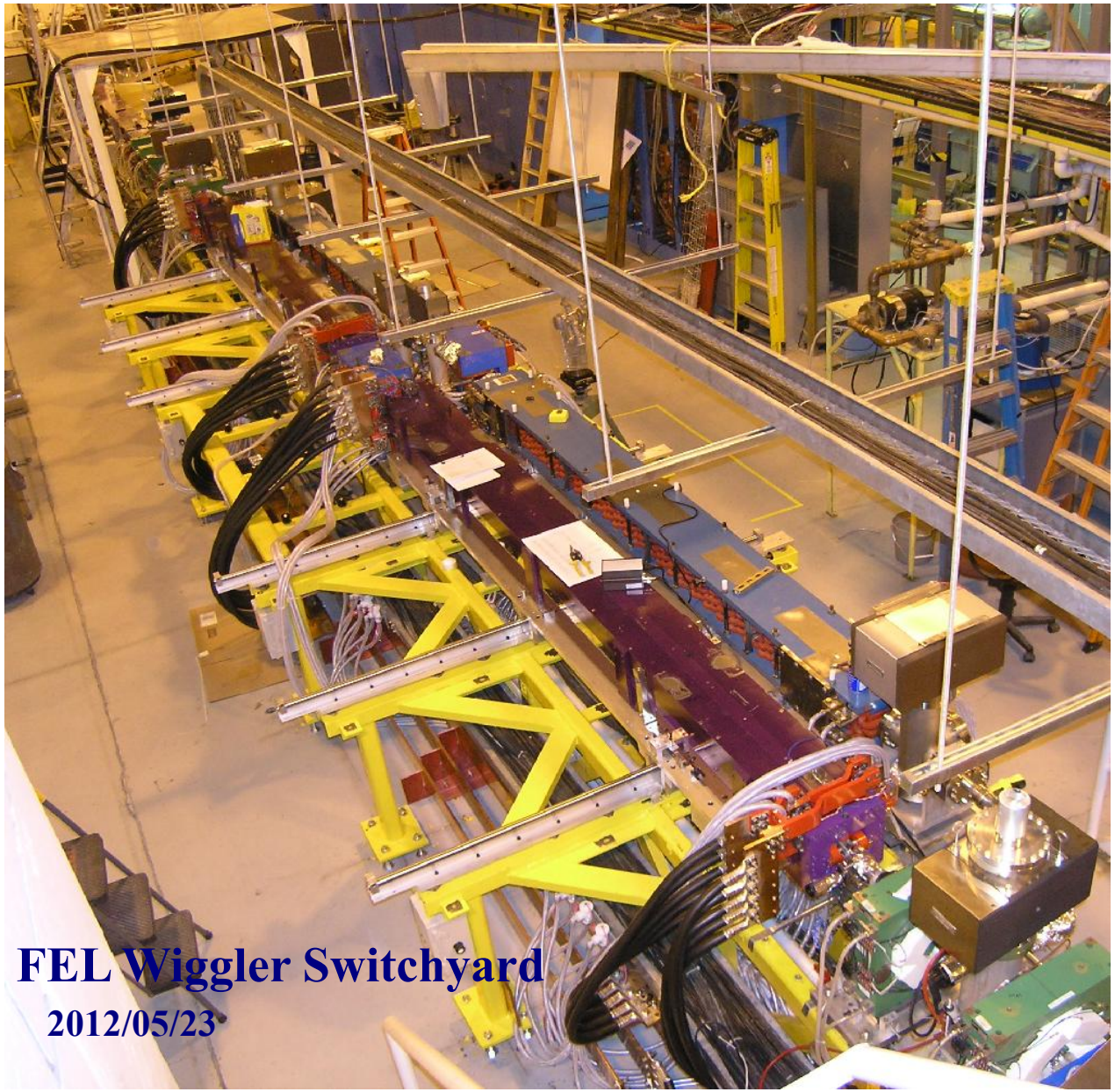
Undulator Switchyard Upgrade



OK-5 + OK-4 + OK-4 + OK-5

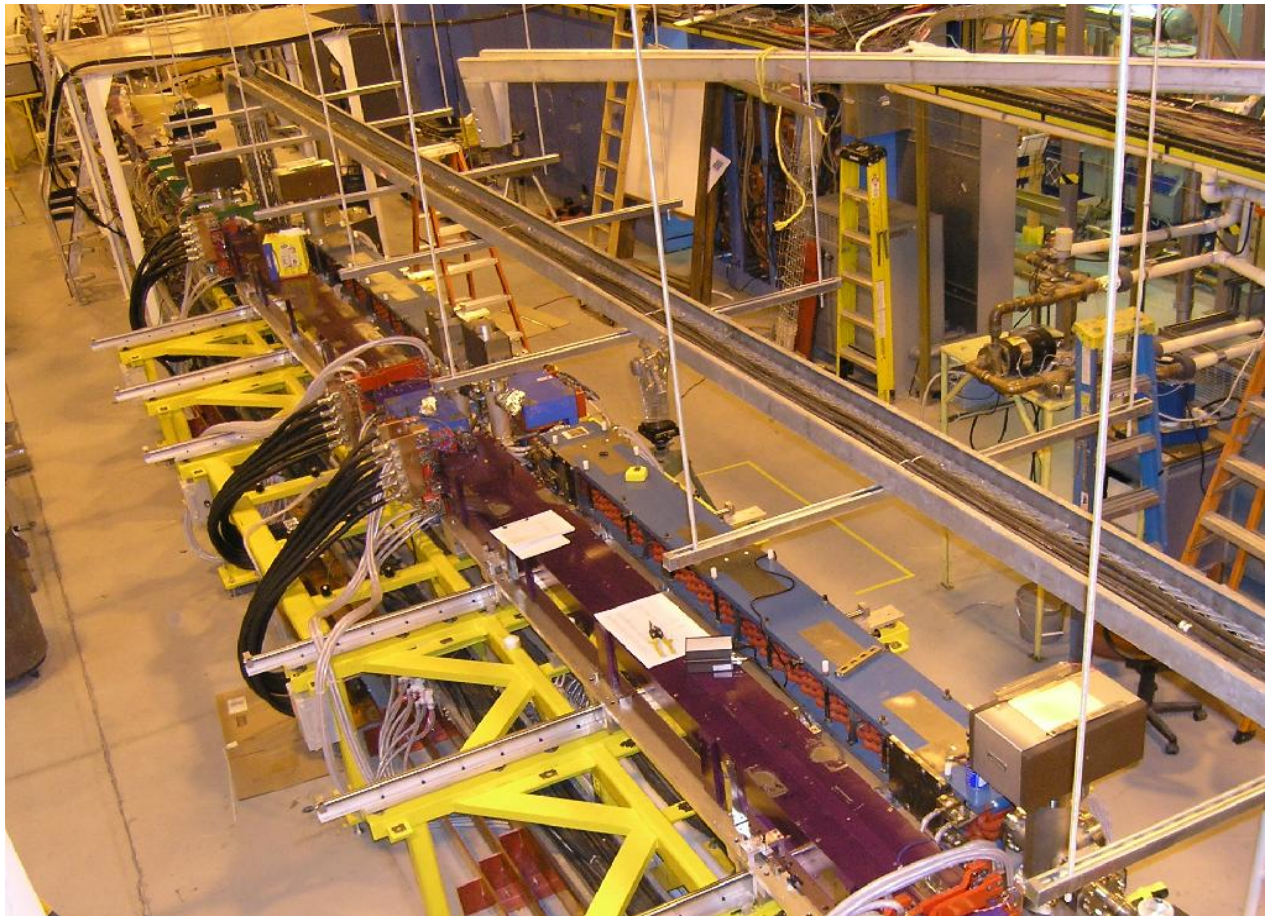
↕

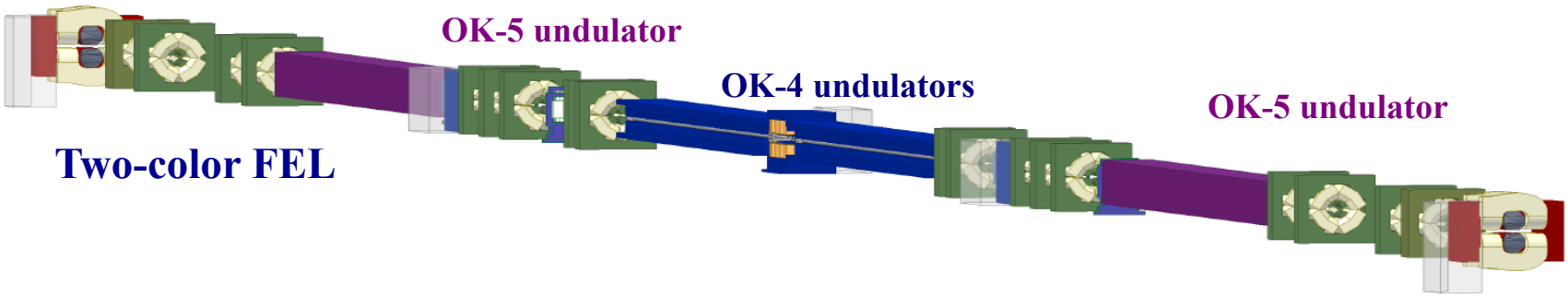
4 * OK-5



FEL Wiggler Switchyard

2012/05/23




OK-5 undulator
OK-4 undulators
OK-5 undulator
Two-color FEL

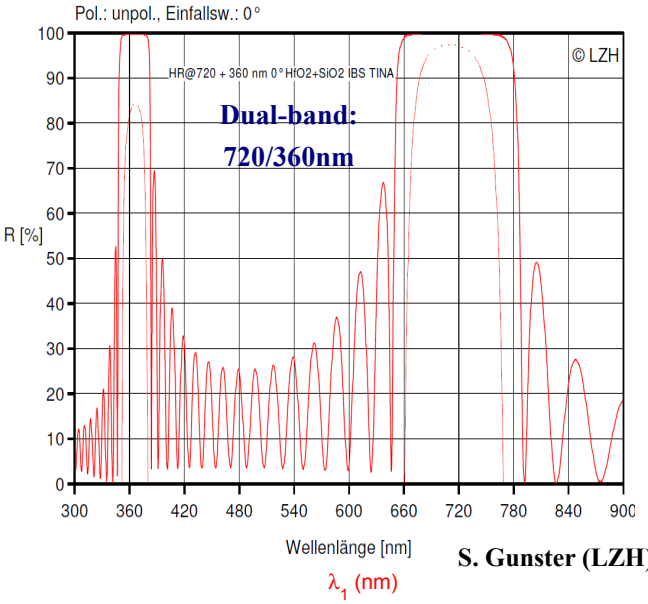
III. Two-color FEL operation at Duke

- **Undulator Configuration**

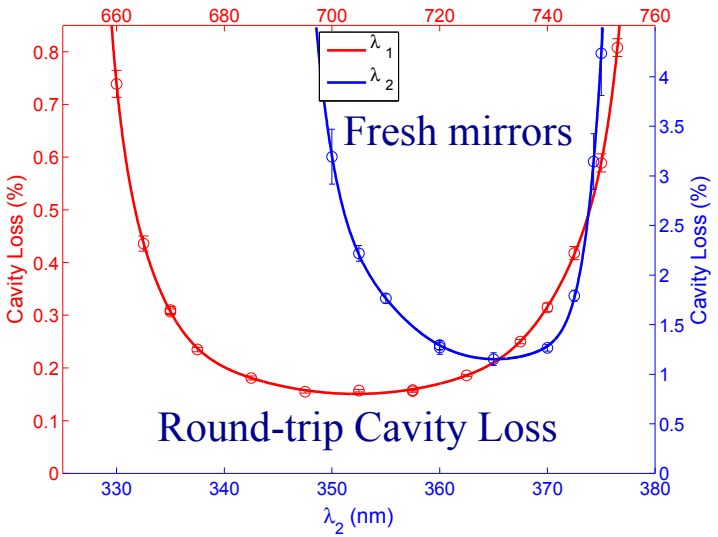
and Dual-band high-reflectivity FEL mirrors

- **Wavelength tuning**
- **Power control**

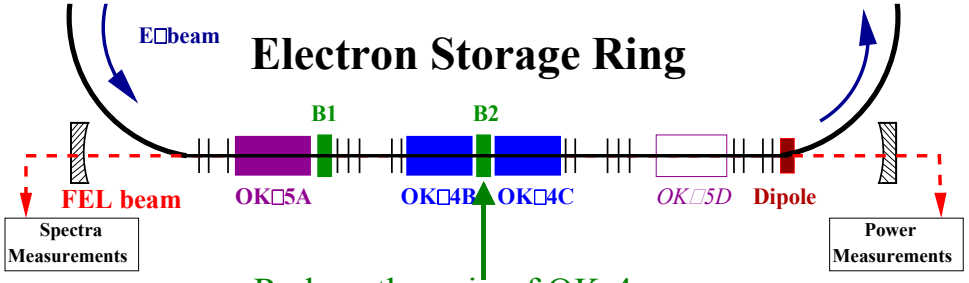
Dual-band FEL mirrors and Undulator Configurations



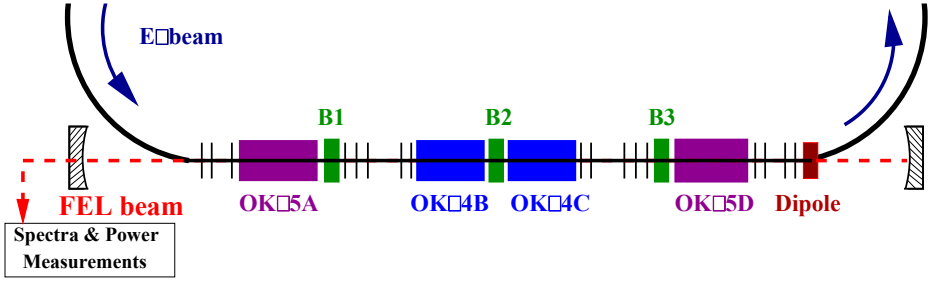
S. Gunster (LZH)



Three-Undulator



Four-Undulator



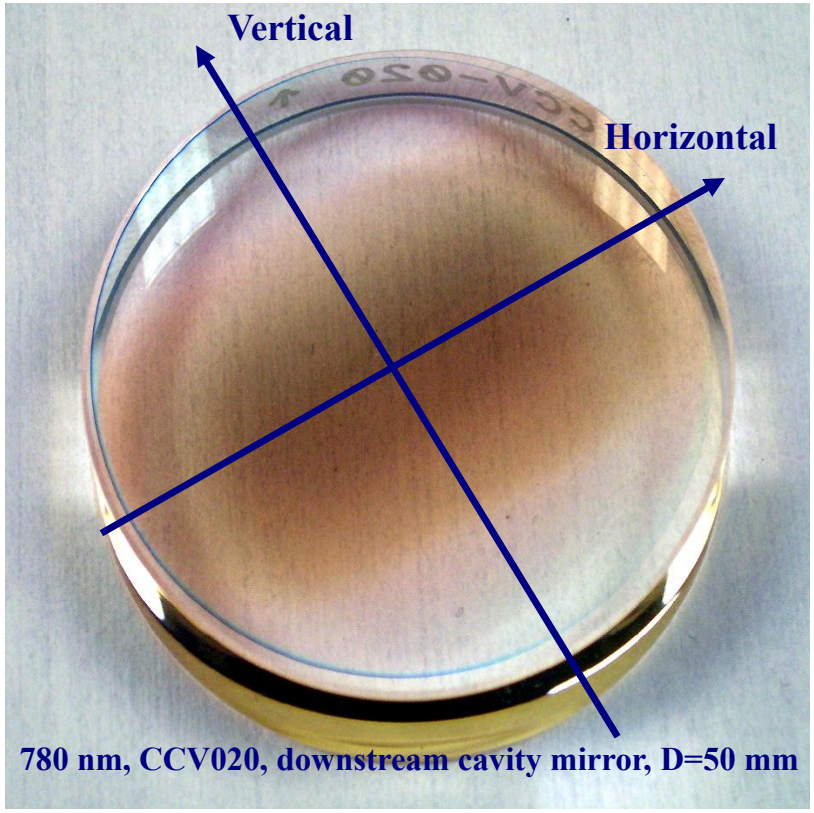
OK5: IR (~ 720 nm)

OK4: UV (~ 360 nm)

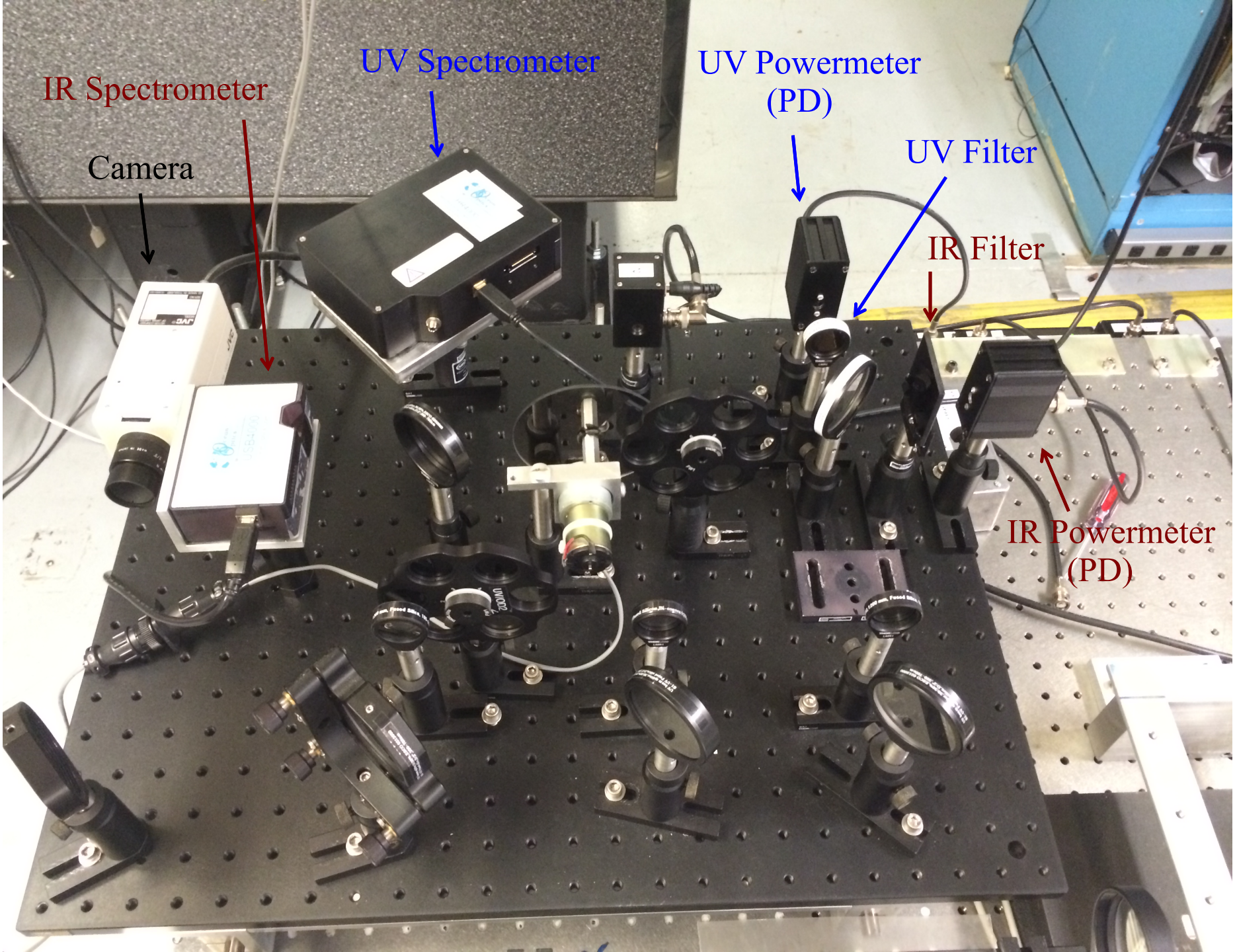
High Reflectivity FEL Mirrors

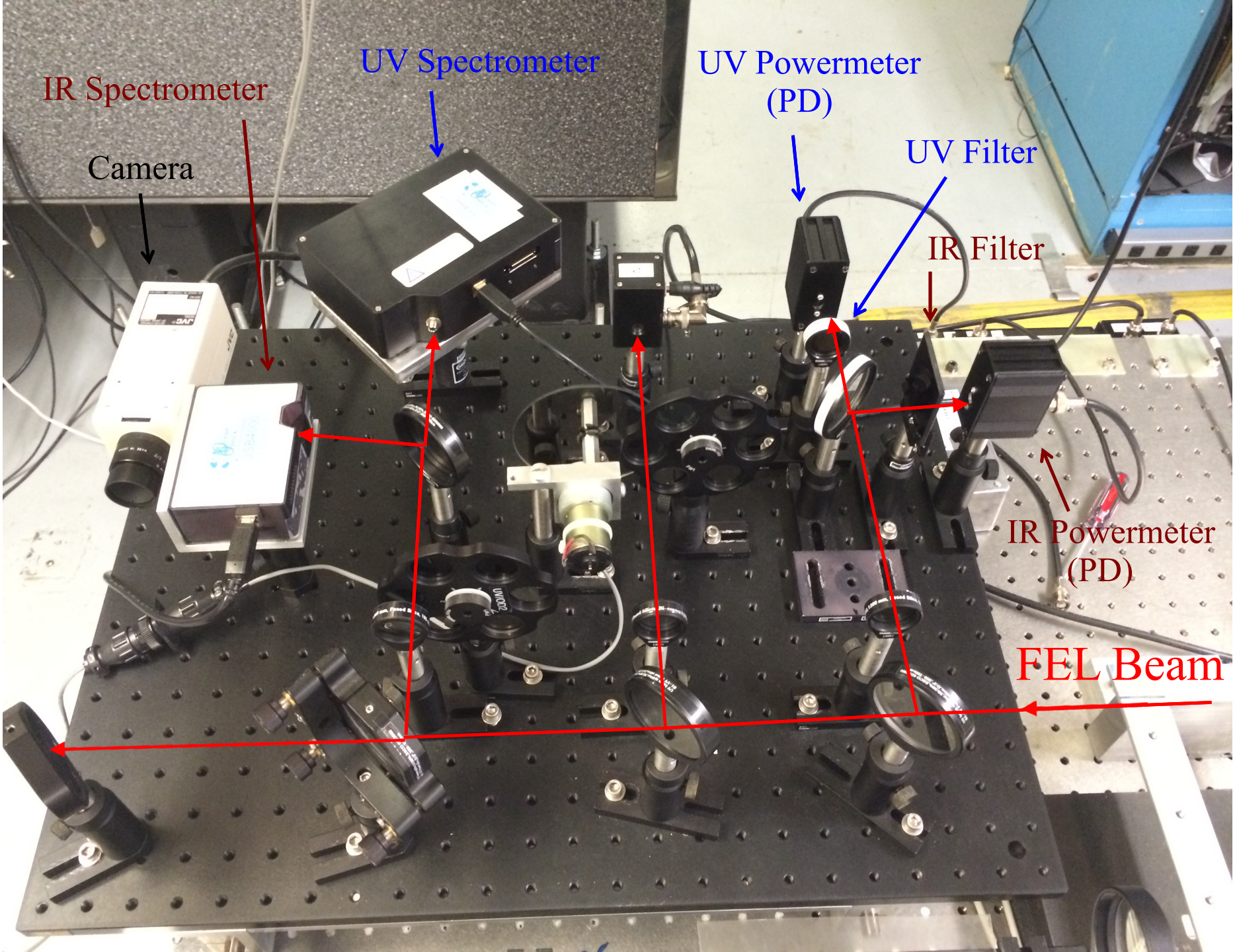
Mirror degradation

Carbon deposition on the surface



Round-trip Cavity Loss: Increased


IR Spectrometer
UV Spectrometer
UV Powermeter
(PD)
Camera
UV Filter
IR Filter
IR Powermeter
(PD)


IR Spectrometer
UV Spectrometer
UV Powermeter
(PD)
Camera
UV Filter
IR Filter
IR Powermeter
(PD)
FEL Beam

III. Two-color FEL operation at Duke

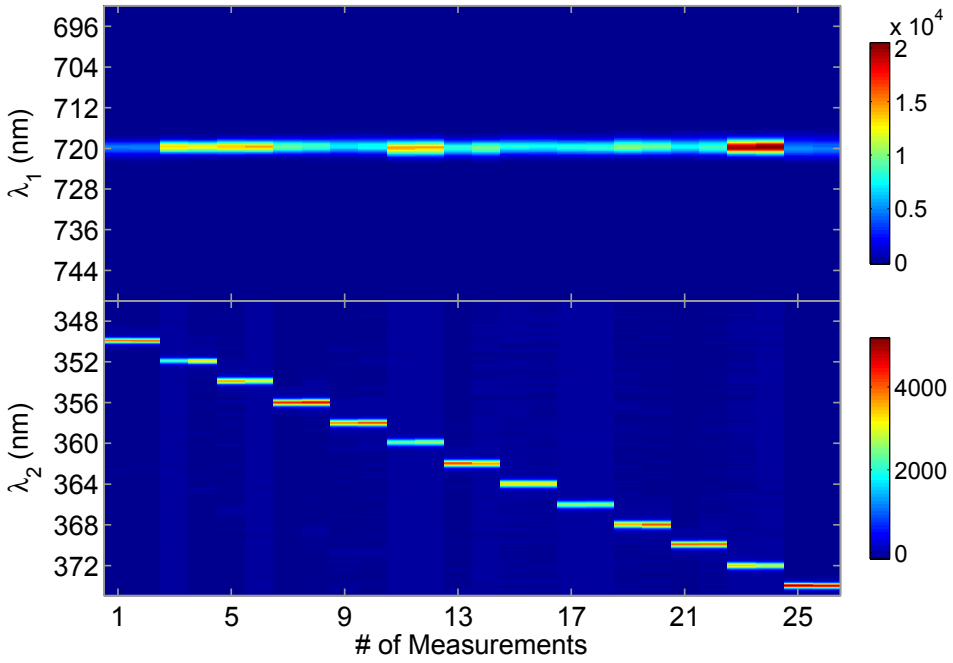
- Undulator Configuration

and Dualband high-reflectivity FEL mirrors

- **Wavelength tuning**
- Power control

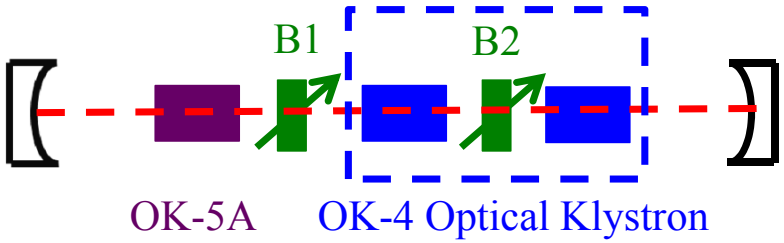
Single Wavelength Tuning: Either IR or UV

Example: UV Tuning

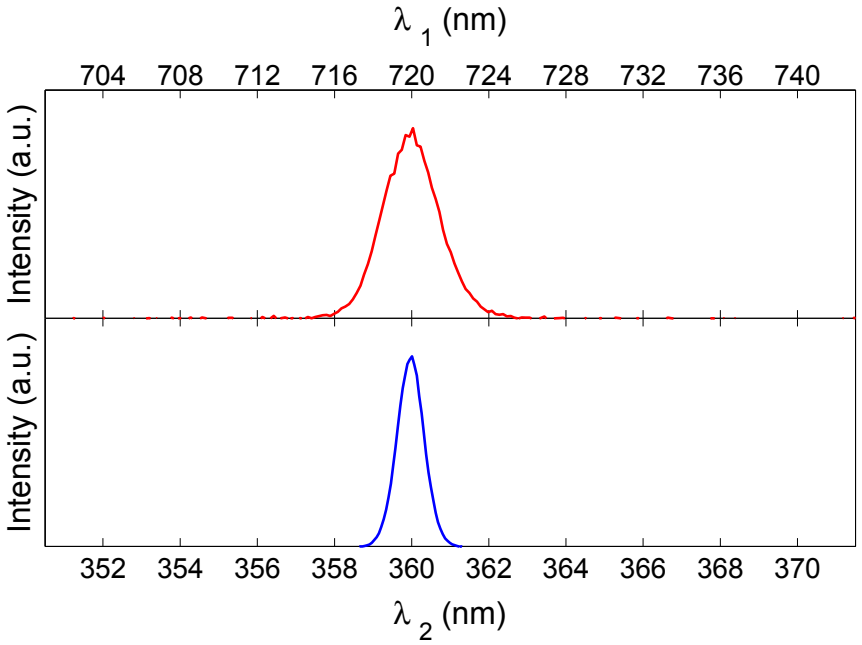


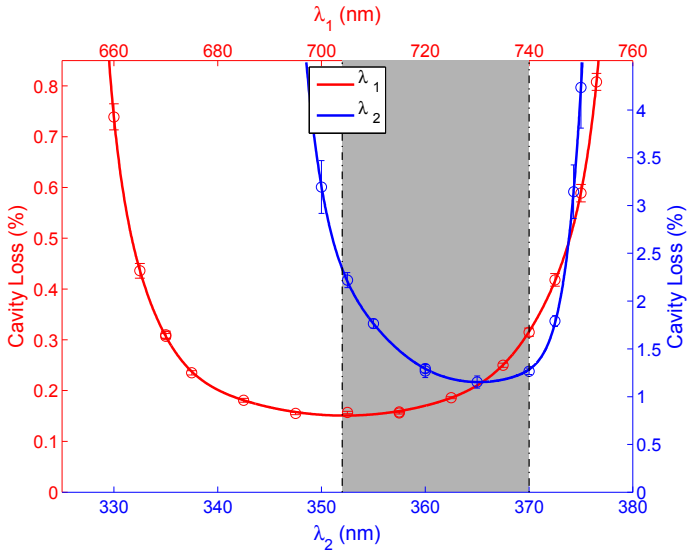
IR: 675 ~ 735 nm ($\Delta\lambda_1 \approx 60$ nm)

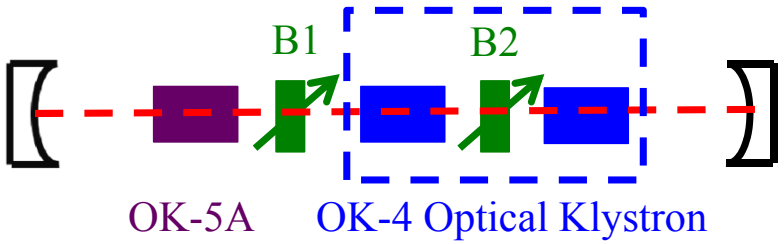
UV: 350 ~ 374 nm ($\Delta\lambda_2 \approx 24$ nm)



Harmonic Wavelength Tuning







IR: 704 ~ 740 nm ($\Delta\lambda_1 \approx 36$ nm)

UV: 352 ~ 370 nm ($\Delta\lambda_1 \approx 18$ nm)

III. Two-color FEL operation at Duke

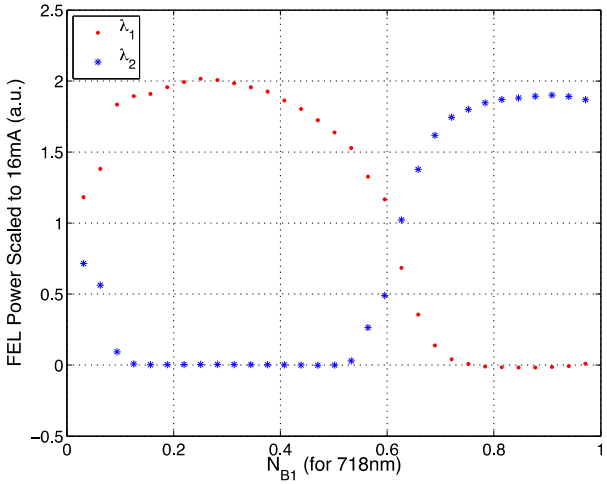
- Undulator Configuration

and Dualband high-reflectivity FEL mirrors

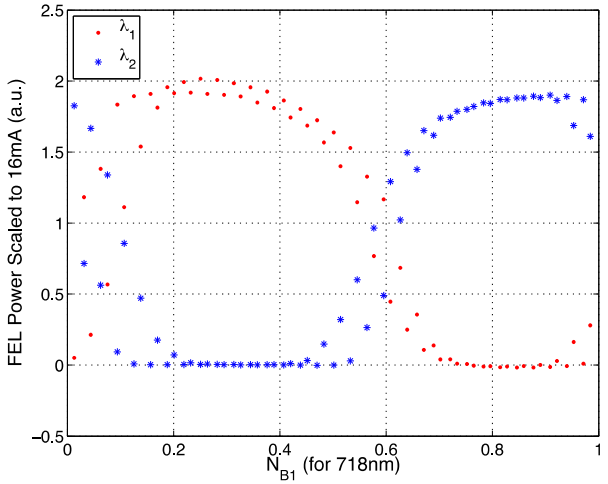
- Wavelength tuning
- **Power control**

Power Control

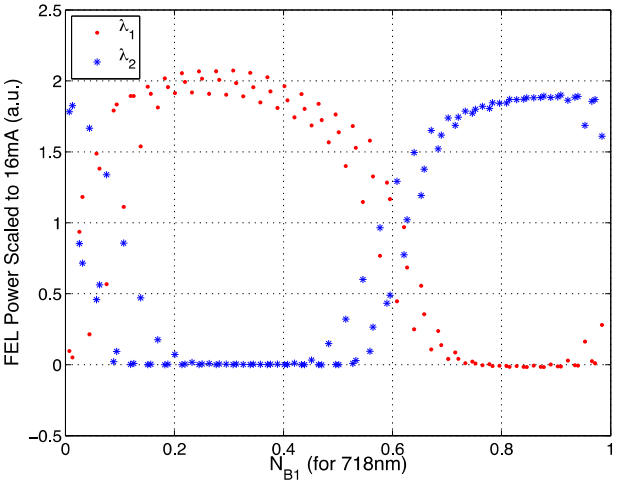
FEL Power: active FEL directly emitted by electron beam.
Red: IR; Blue: UV.



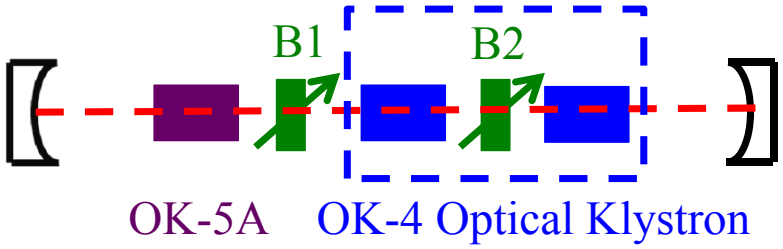
N_{B1} tuned: 0 to 1



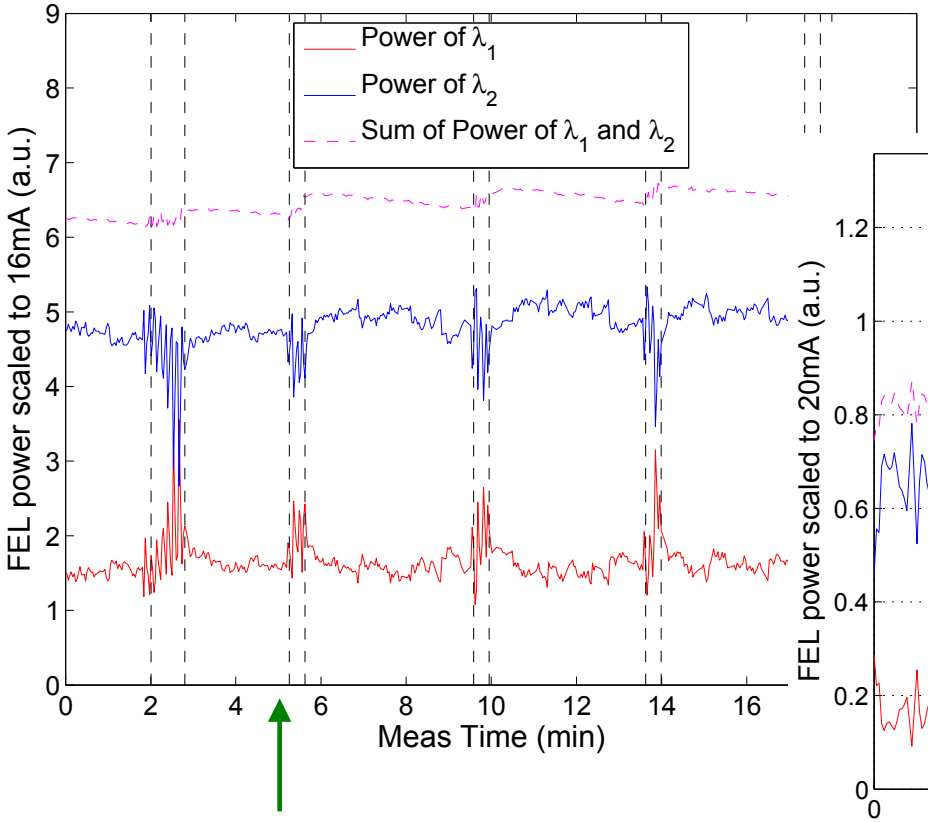
N_{B1} tuned:
(0 to 1) + (1 to 2),
overlapped

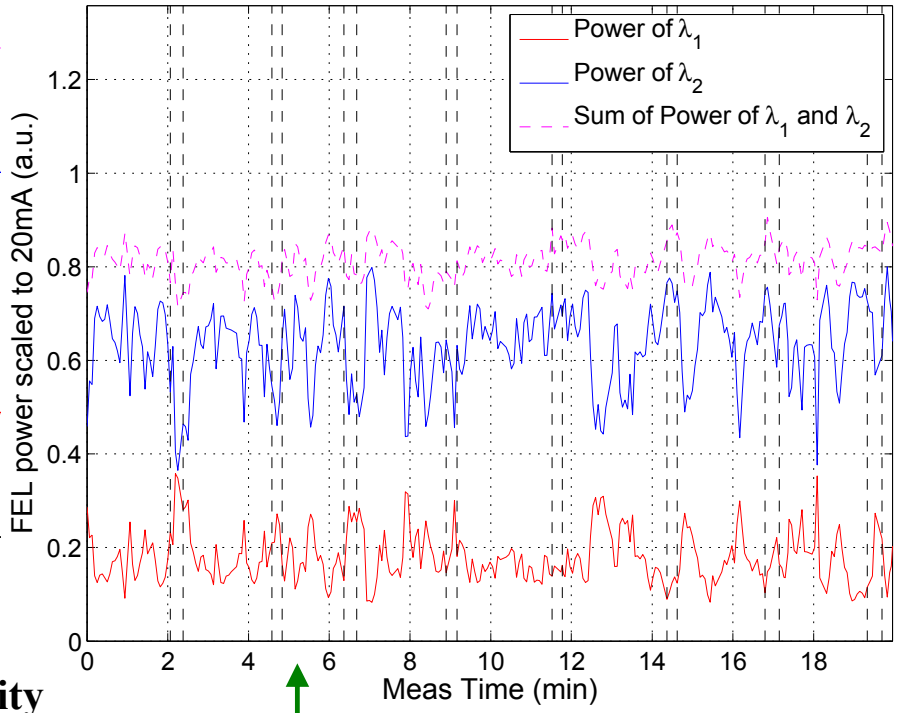


N_{B1} tuned:
(0 to 1) + (1 to 2) + (2 to 3),
overlapped



Power Control (Power Stability)





Fresher Mirrors, better temperature stability (Winter):

UV Power: 3.9% (rms)
IR Power: 8.0%
Total Power: 2.3%

Degraded Mirrors, poorer temperature stability (Summer):

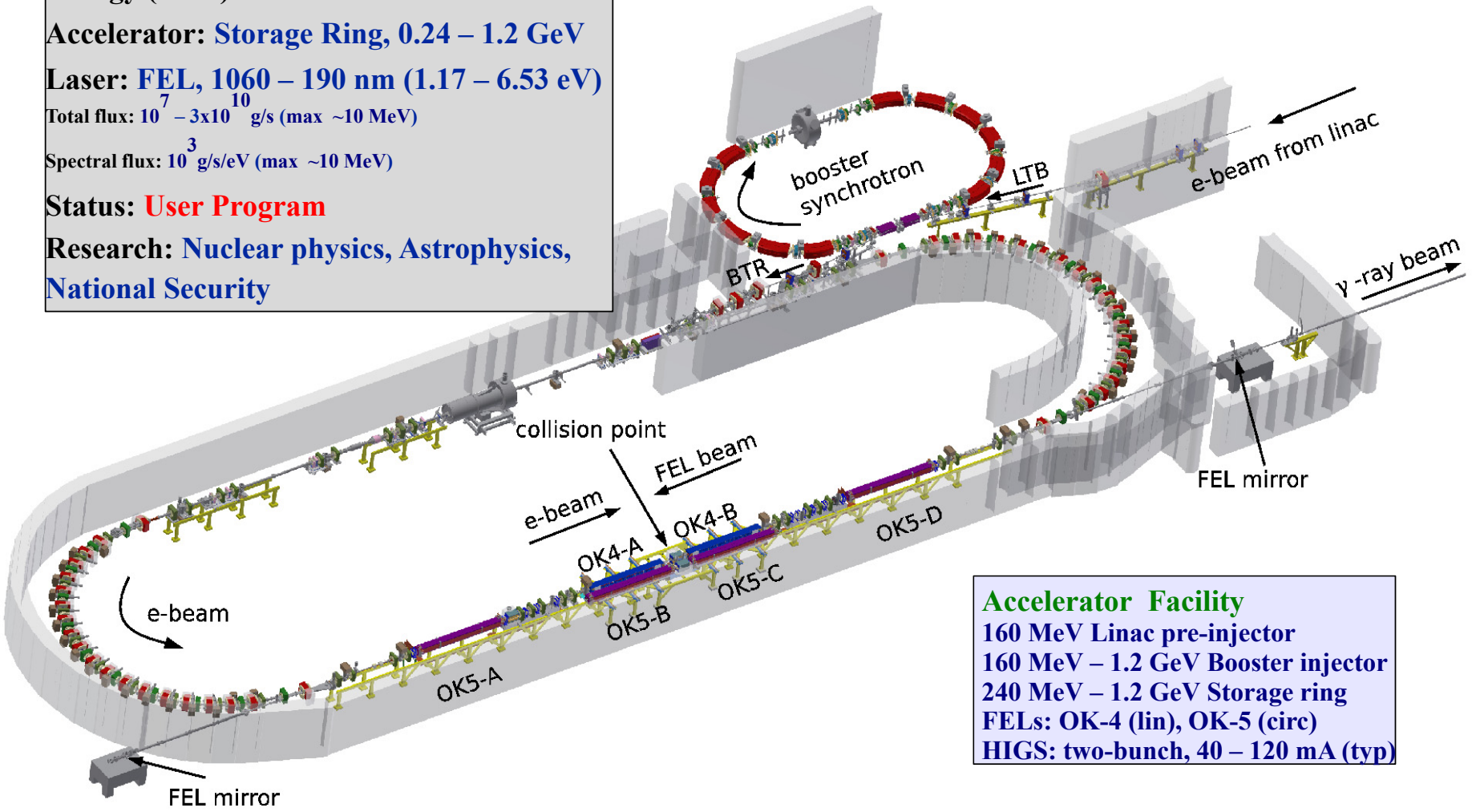
UV Power: 13.0%
IR Power: 29.2%
Total Power: 4.3%

IV. Two-color Gamma-ray production at HIGS

The High Intensity Gamma-ray Source (HIGS) at Duke

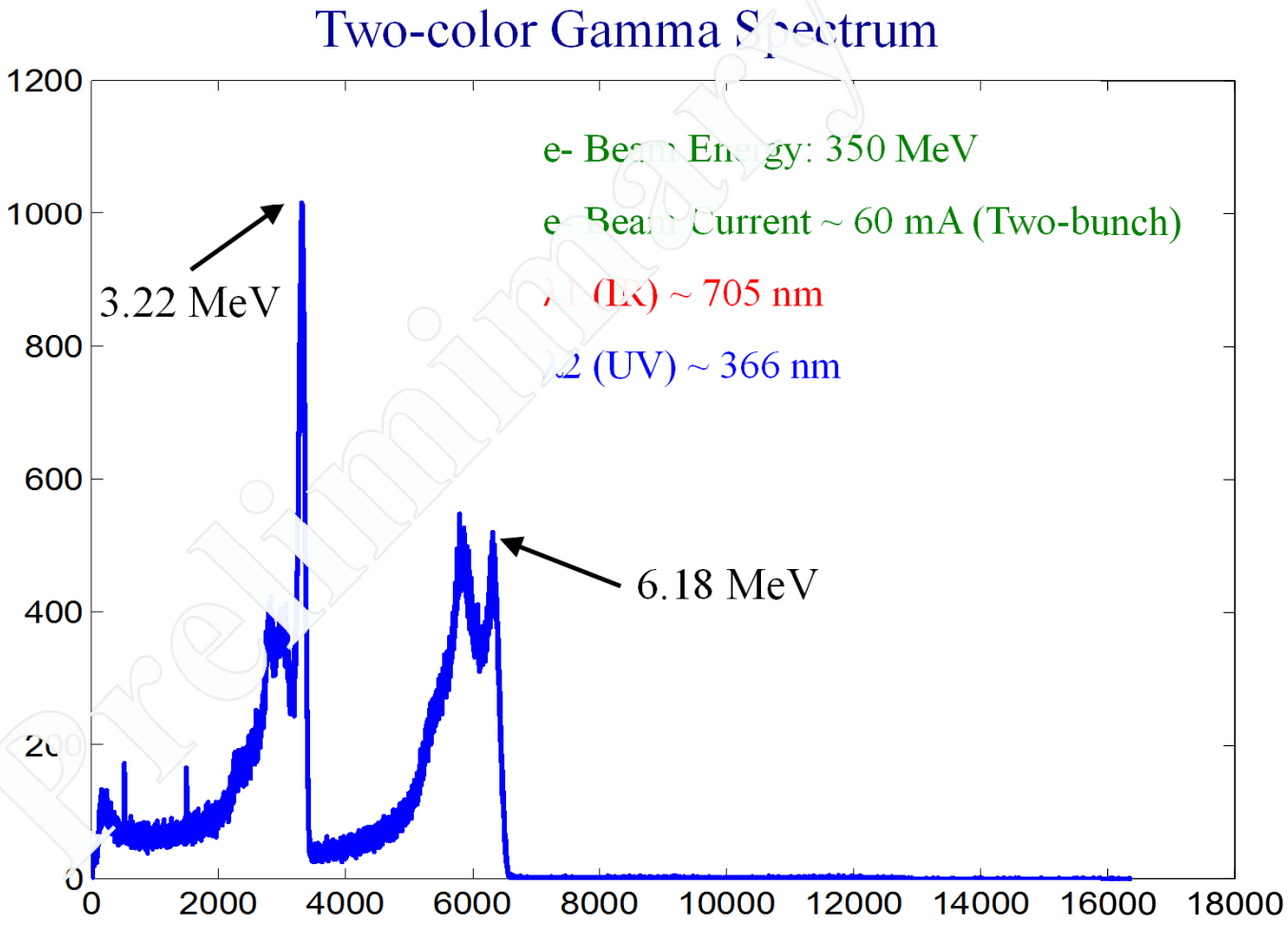
Facility/Project: HIGS
Institution: TUNL and Duke University
Country: US
Energy (MeV): 1 – 100
Accelerator: Storage Ring, 0.24 – 1.2 GeV
Laser: FEL, 1060 – 190 nm (1.17 – 6.53 eV)
Total flux: 10^{7} – 3×10^{10} g/s (max ~10 MeV)
Spectral flux: 10^{3} g/s/eV (max ~10 MeV)
Status: User Program
Research: Nuclear physics, Astrophysics, National Security

HIGS
An Electron -Photon Collider



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)

Two-color Gamma-ray Production



Courtesy of F. Krishichayan and W. Tornow

Summary

- Successful operation of a two-color storage ring FEL (Dual-band FEL mirrors; a three-undulator configuration or a four-undulator configuration)
- Wavelength tunability with a wide tuning range (Single wavelength tuning; harmonic lasing tuning)
- Full control of FEL power in two colors while maintaining total power at a steady level
- Two-color gamma-ray production using HIGS

More details on Poster WEP033 (Y. K. Wu et al.)

Thank You!