A VUV FEL for Producing 70 – 100 MeV Circularly Polarized Compton Gamma-ray Beams

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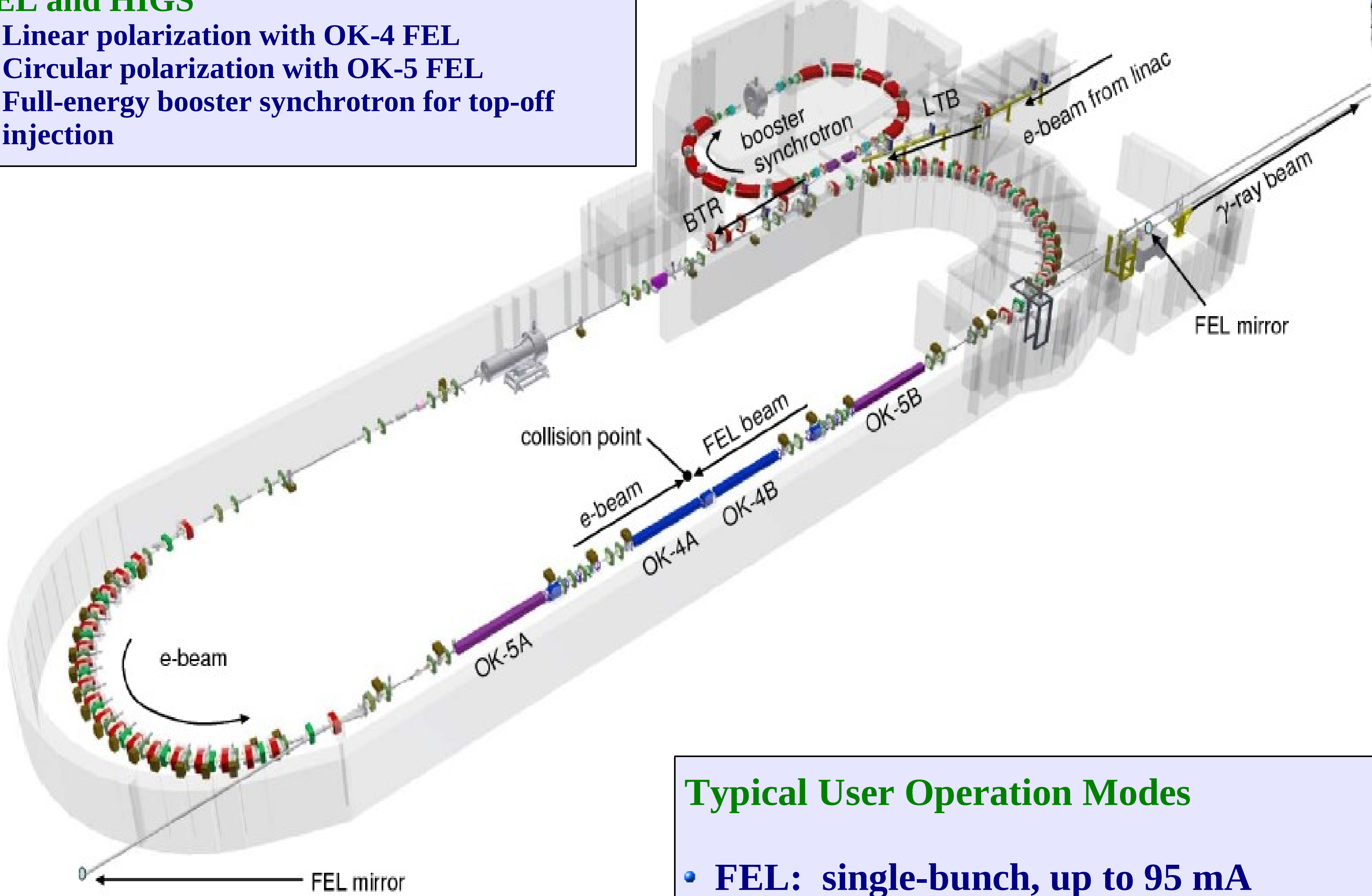
Outline

VUV FEL Research and High Energy Gamma-ray Beams

- Overview of Duke FEL Lab Accelerator Facility
- New VUV FEL Development: 190 nm lasing
- VUV FEL Driven Compton Gamma-ray Beams: 70 – 100 MeV
- Research Programs using HIGS Beams
- VUV FEL Upgrade

Layout of the Duke FEL Lab Accelerator Facility

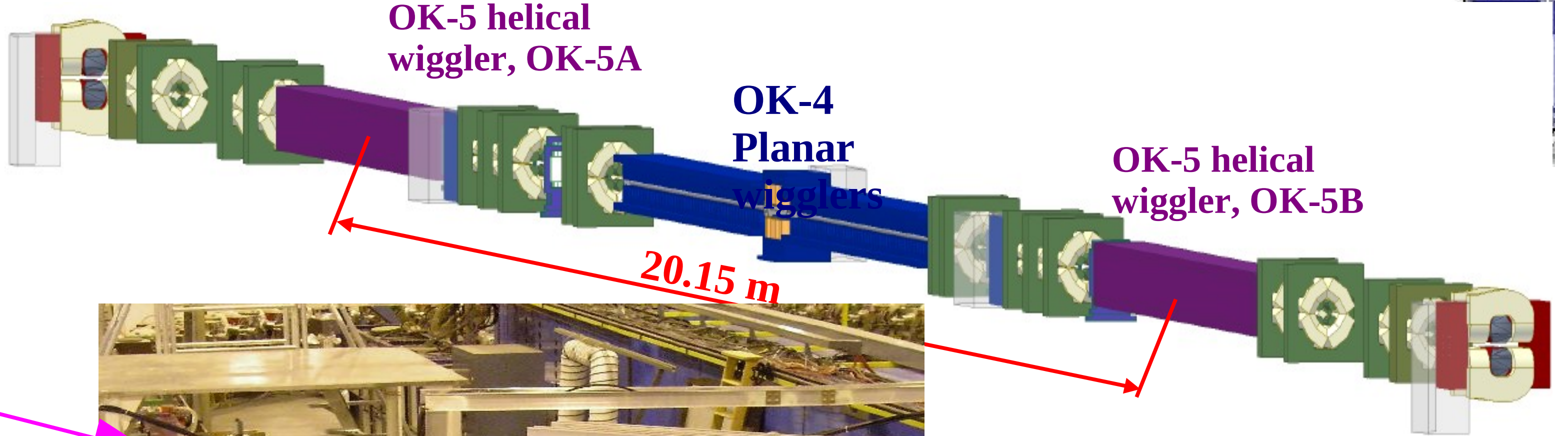
FEL and HIGS
- Linear polarization with OK-4 FEL
- Circular polarization with OK-5 FEL
- Full-energy booster synchrotron for top-off injection

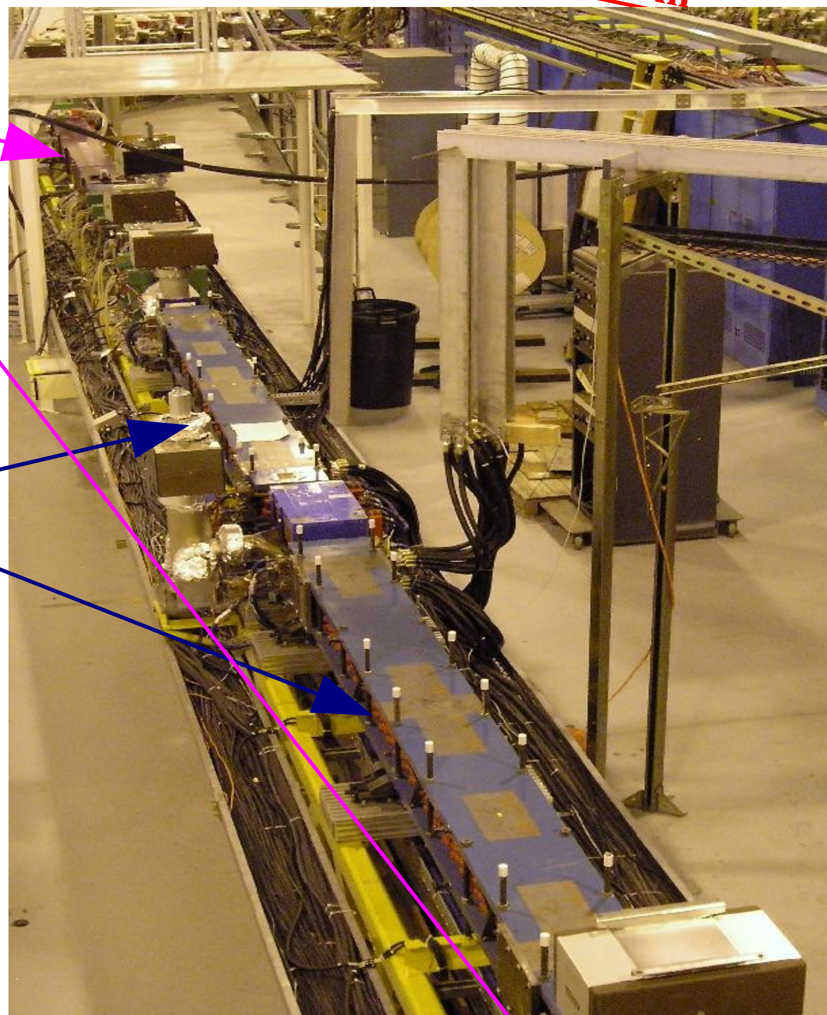


Typical User Operation Modes

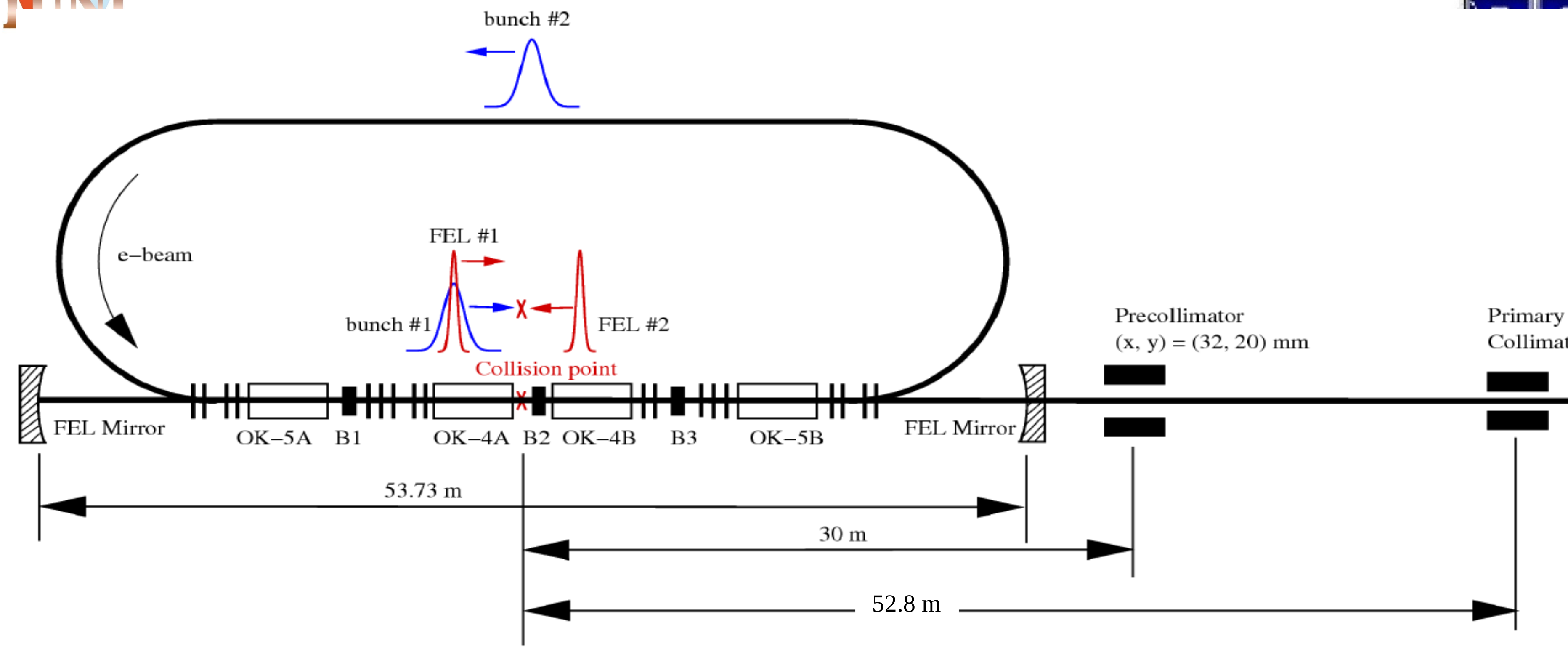
- FEL: single-bunch, up to 95 mA
- HIGS: two-bunch, typical 80 - 110 mA

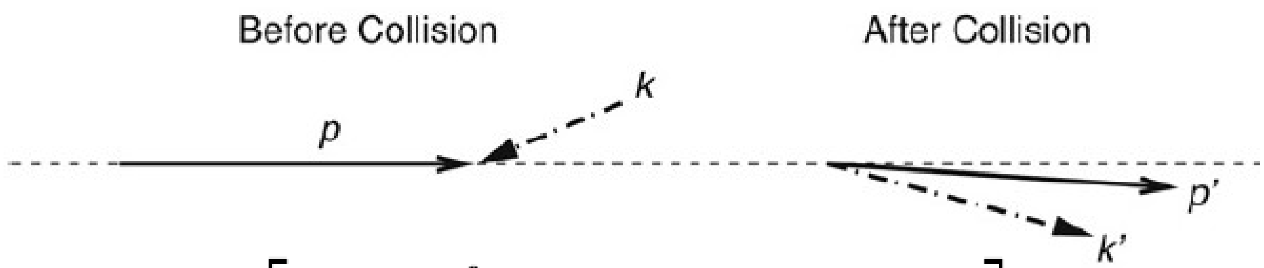
OK-5 and OK-4 FELs (Since Aug. 2005)





FEL and HIGS Modes of Operation



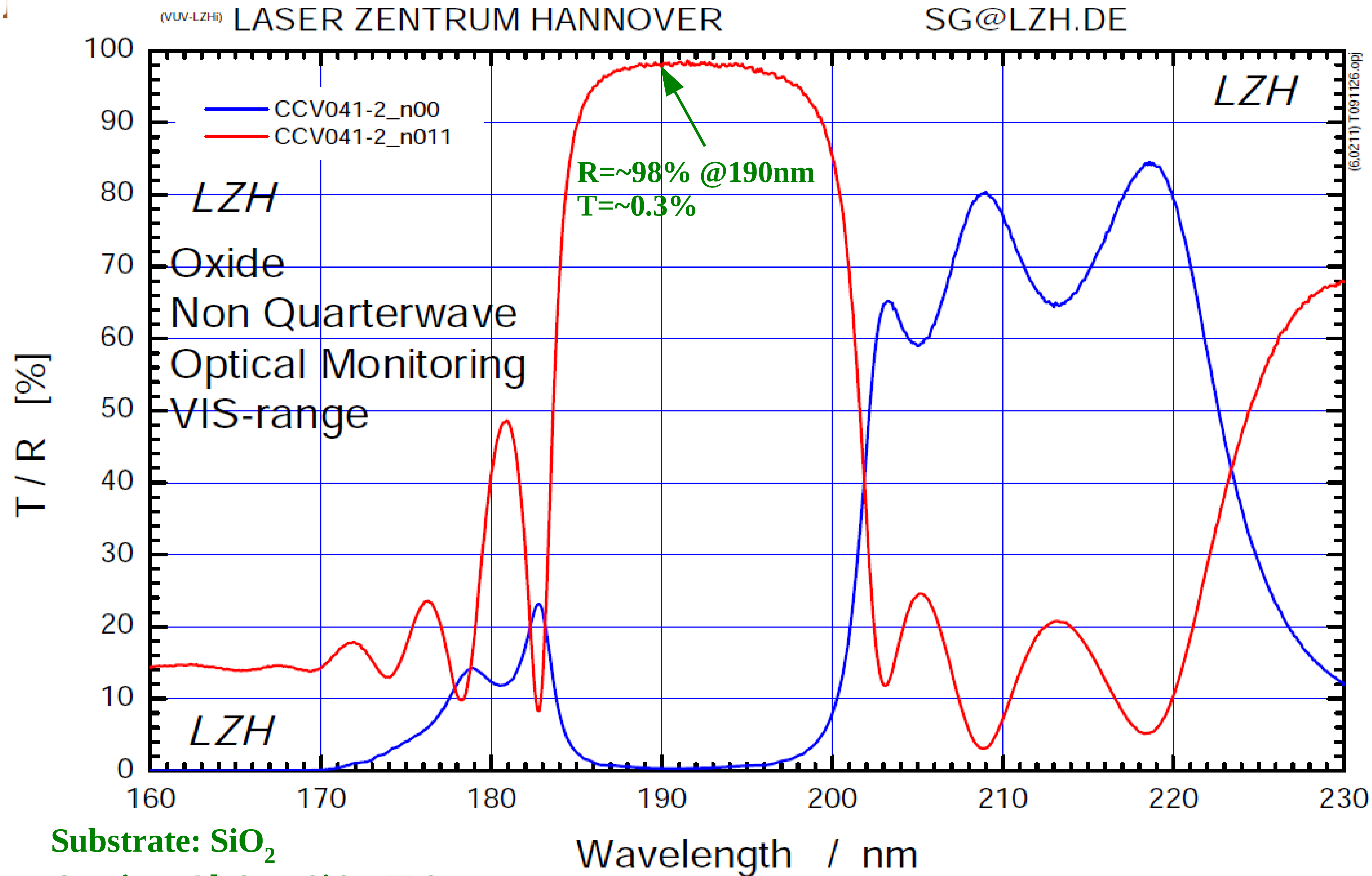


$$E_\gamma \equiv \hbar\omega' = \frac{\hbar\omega(1-\beta\cos\theta_i)}{1-\beta\cos\theta_f+\frac{\hbar\omega}{\varepsilon_e}(1-\cos\theta_{ph})}$$

$$d\sigma = 8\pi r_e^2 \frac{dy}{x^2}\left[\left(\frac{1}{x}-\frac{1}{y}\right)^2+\left(\frac{1}{x}-\frac{1}{y}\right)+\frac{1}{4}\left(\frac{x}{y}+\frac{y}{x}\right)\right]$$

$$x = \frac{2\gamma\hbar\omega(1-\beta\cos\theta_i)}{mc^2}, \qquad y = \frac{2\gamma\hbar\omega'(1-\beta\cos\theta_f)}{mc^2}$$

190 nm Mirrors: Reflectivity and Transmission

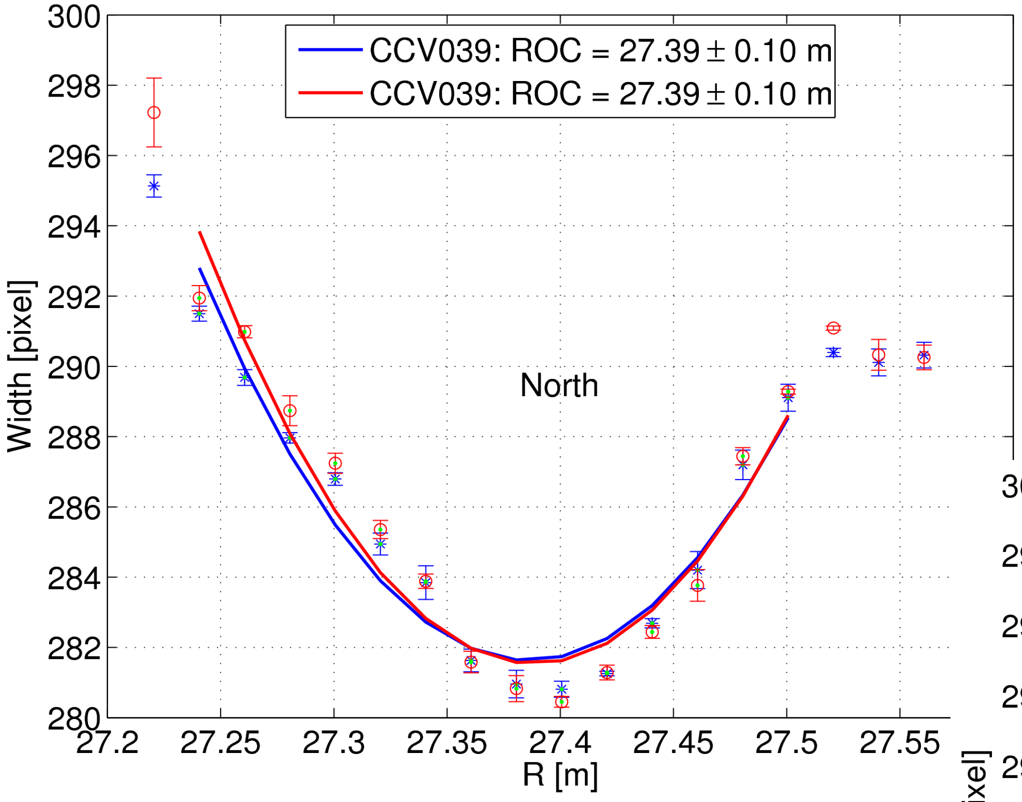


Substrate: SiO_2

Coating: Al_2O_3 – SiO_2, IBS

Courtesy of Stefan Günster, LZH

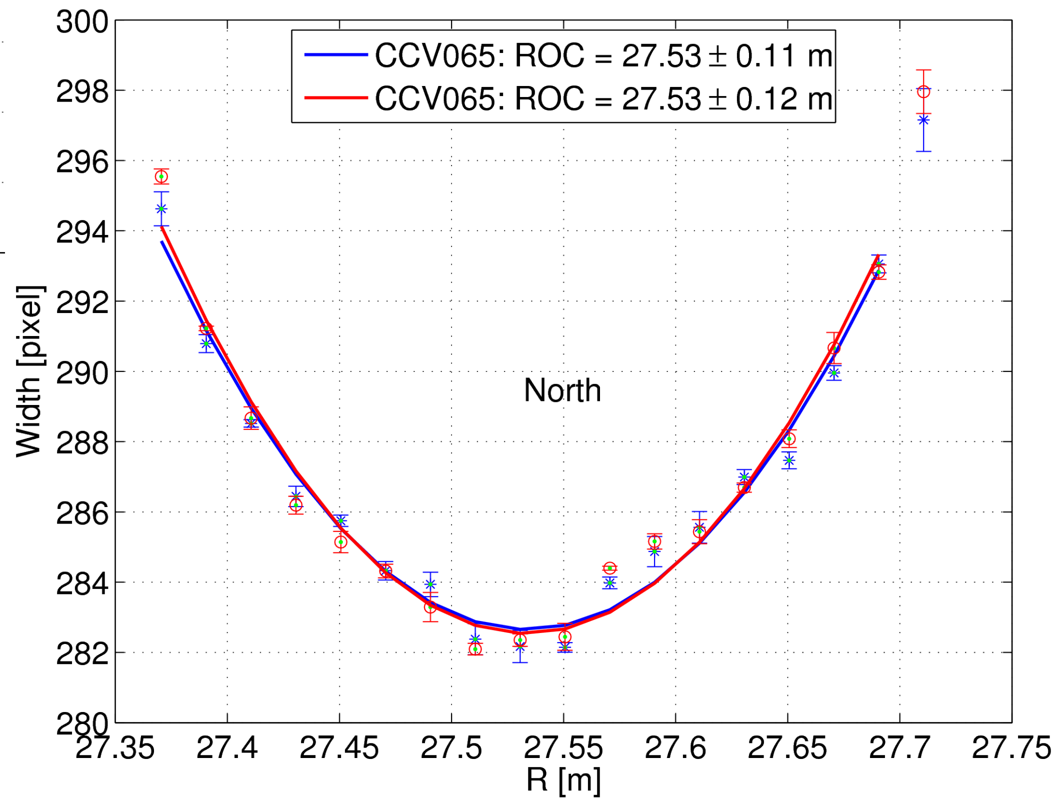
ROC Measurements: 190 nm Mirrors



Nearly Concentric FEL Resonator (L/2 = 26.865 m)

Measured 190 nm mirror ROC: 27.4 – 27.5 m

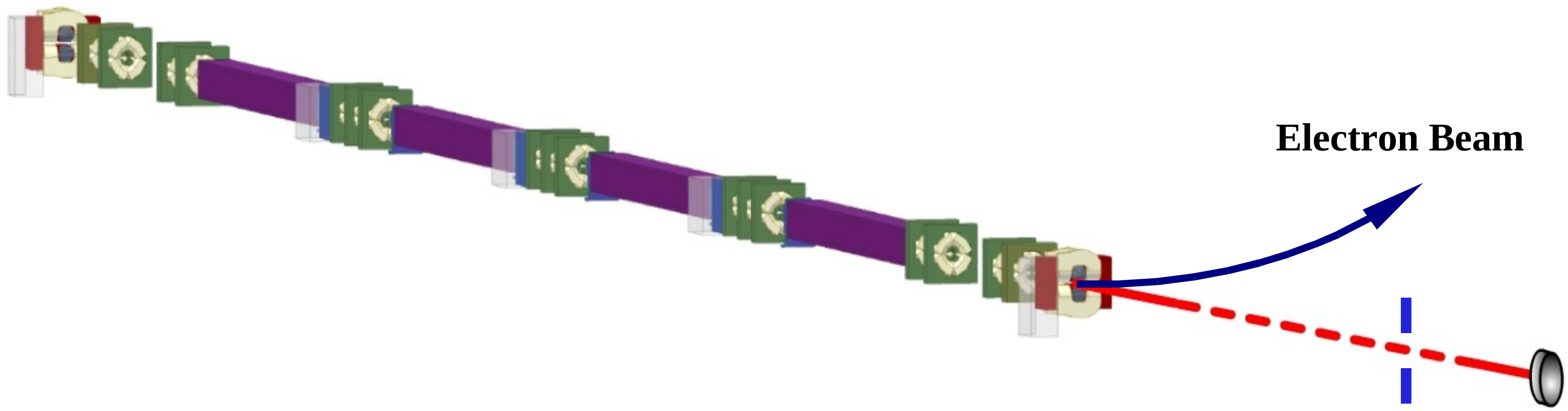
Z_R = ~ 4 m;

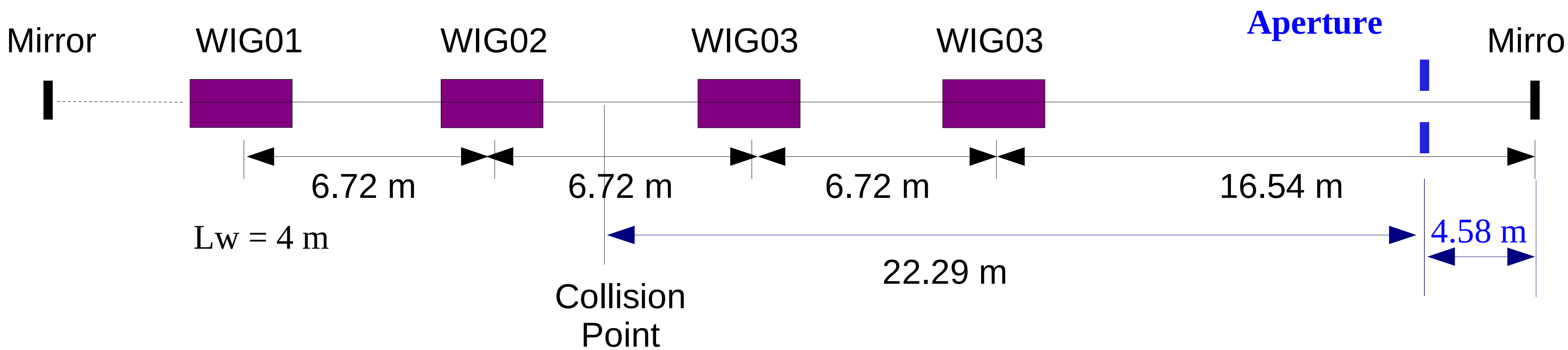


Improving Resonator Stability: In-cavity Apertures

Mirror Surface Deformation:

Wiggler higher-order harmonic power loading

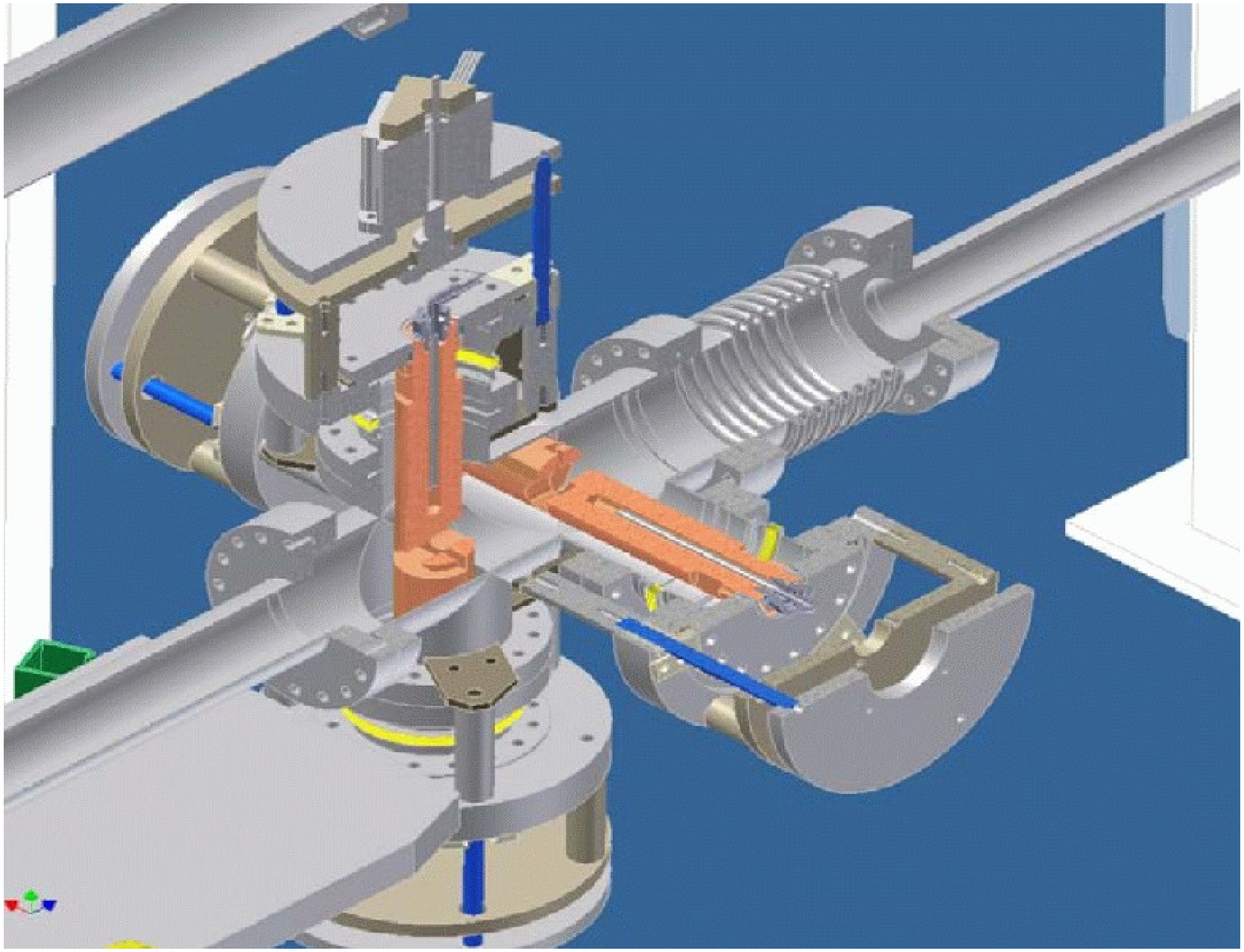




Improving Resonator Stability: In-cavity Apertures

In-cavity, Water-cooled apertures for Harmonic Radiation Control

Harmonic Power Reduction: about two orders of magnitude for helical wigglers

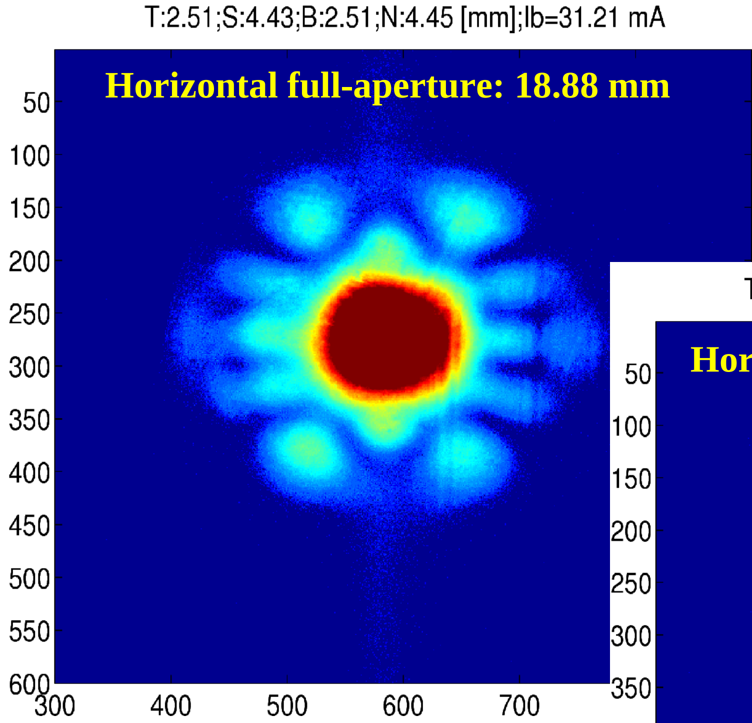


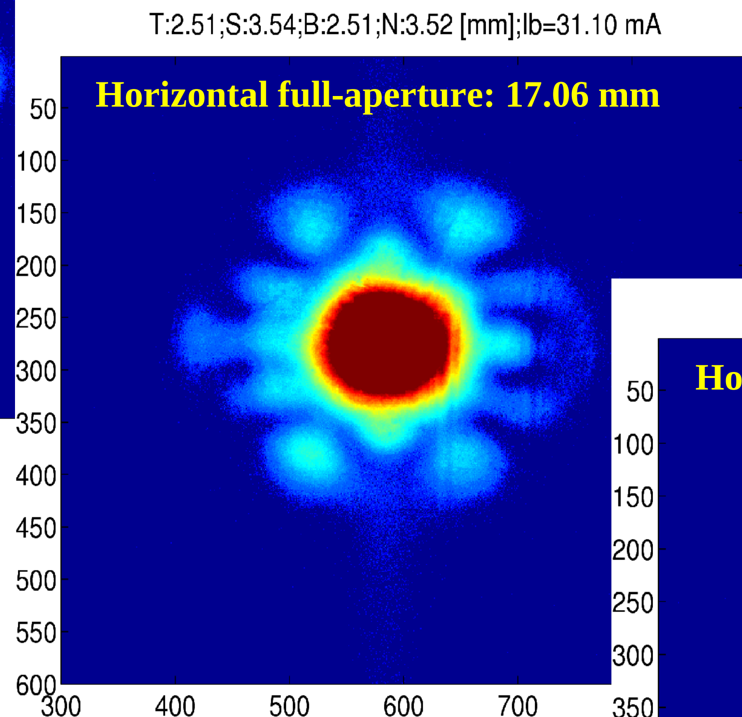
Commissioned for User Operation (Sep., 2008)

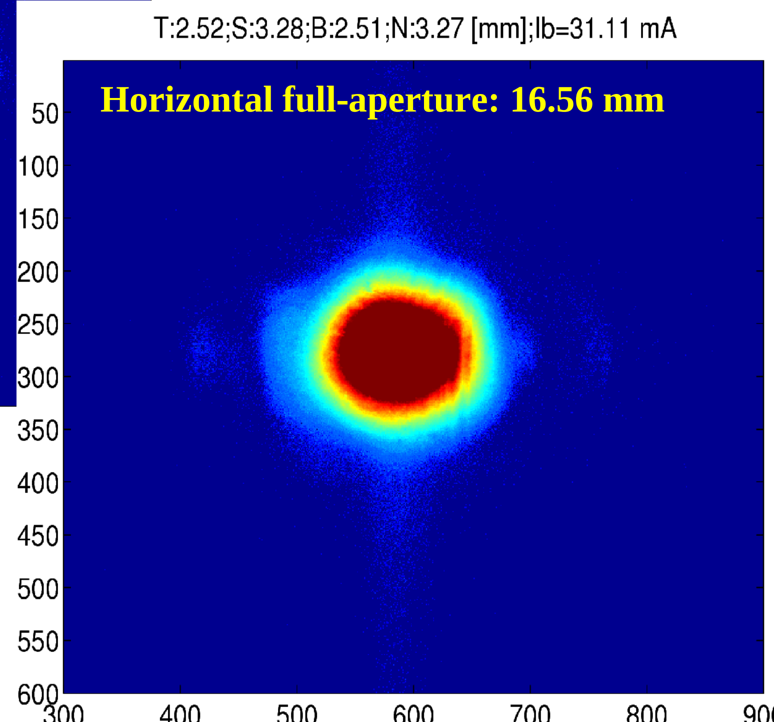
Part of Ph.D. thesis work of Senlin Huang

Reducing Mirror Deformation

FEL transverse mode restored to TEM00-like by closing the horizontal aperture

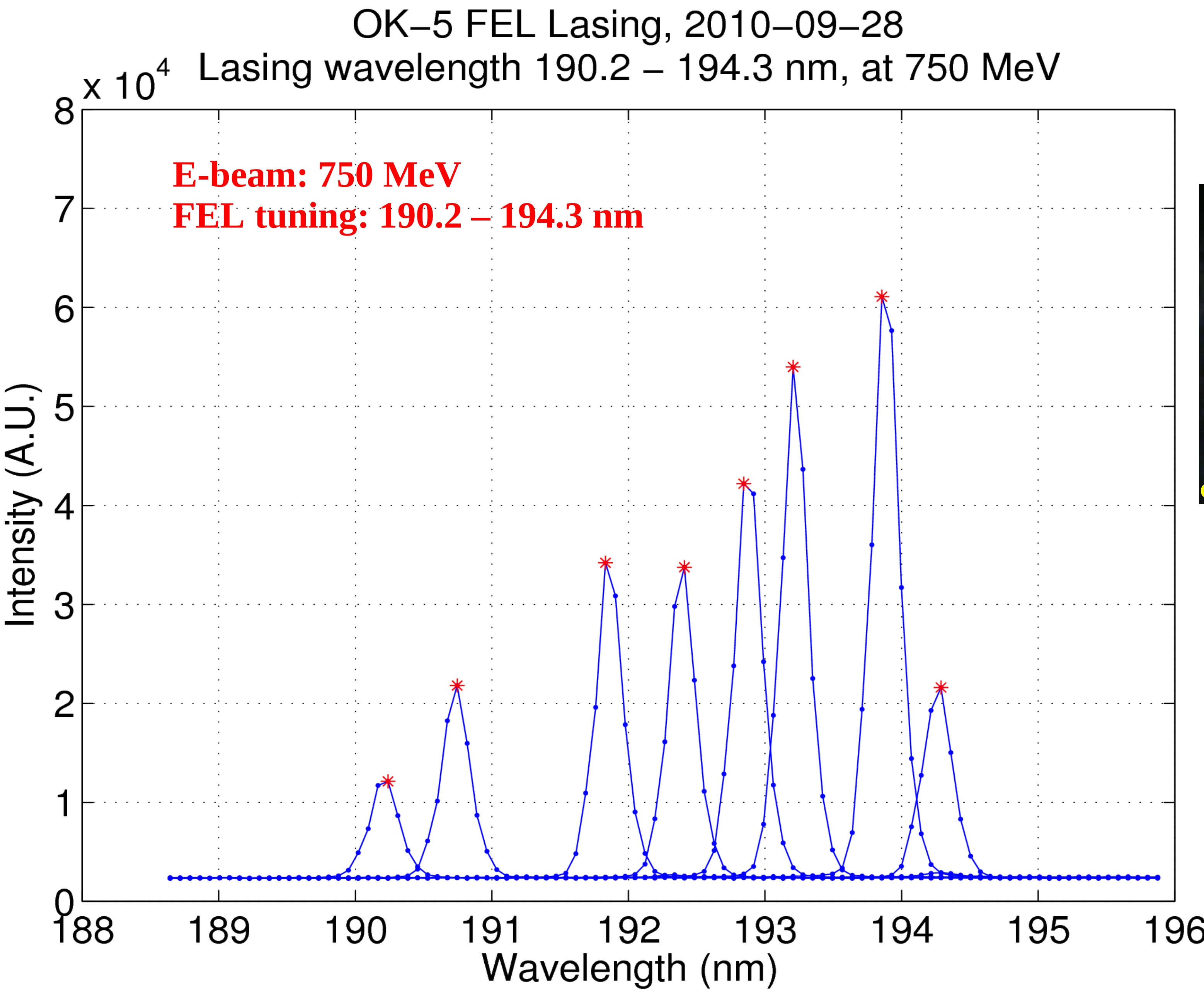


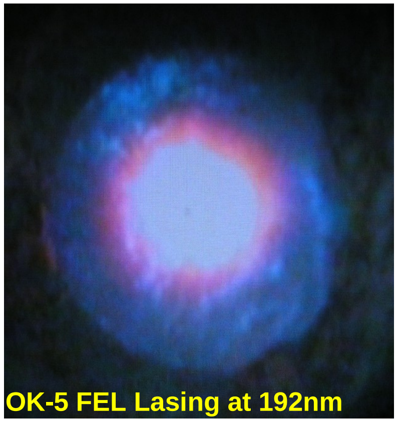




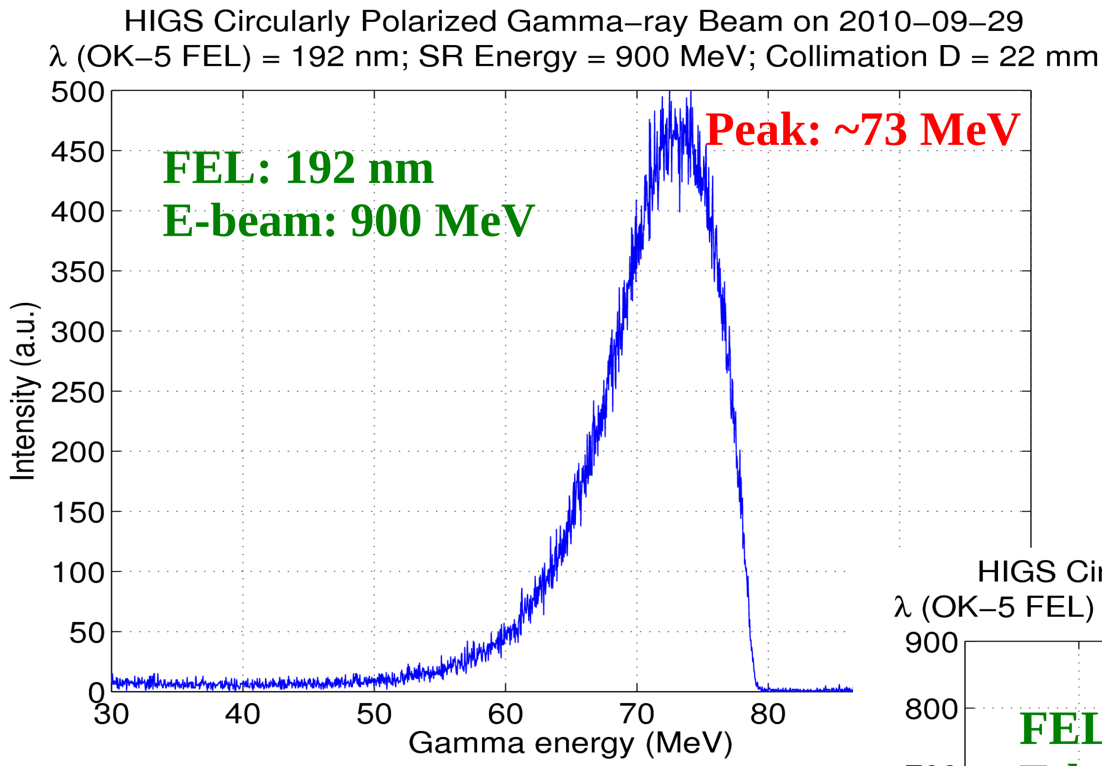
31 mA, 825 MeV 2-bunch beam, with helical OK-5 FEL

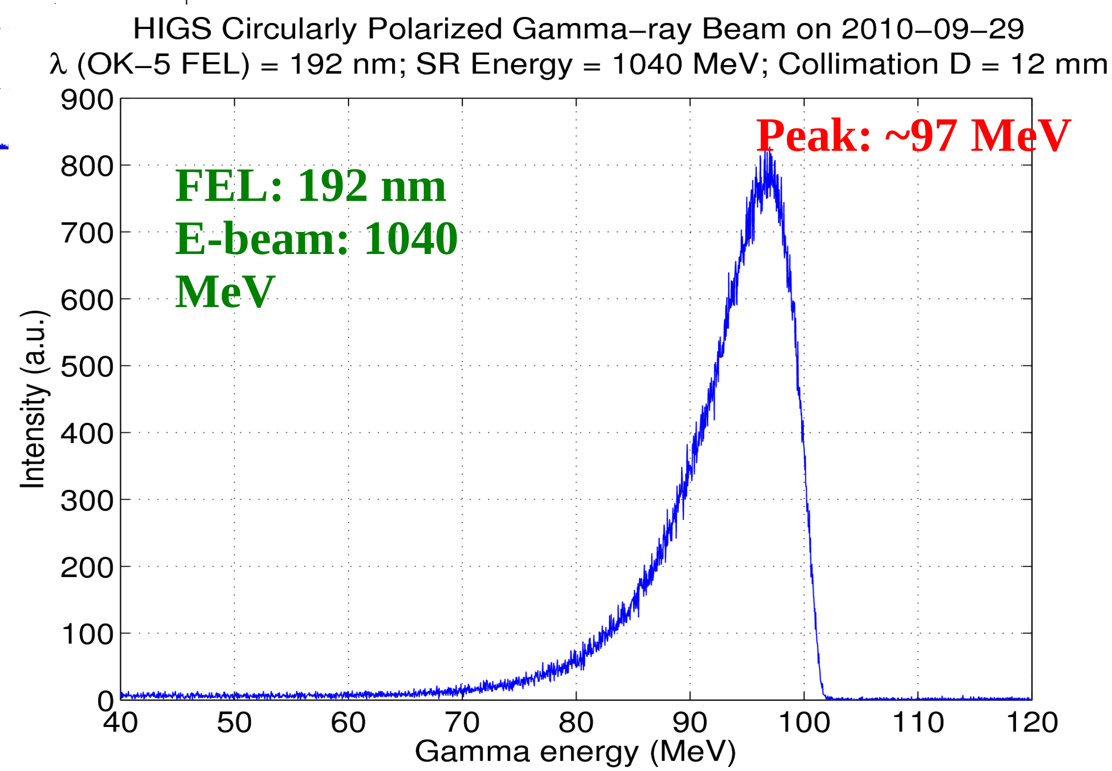
190 nm FEL Tuning





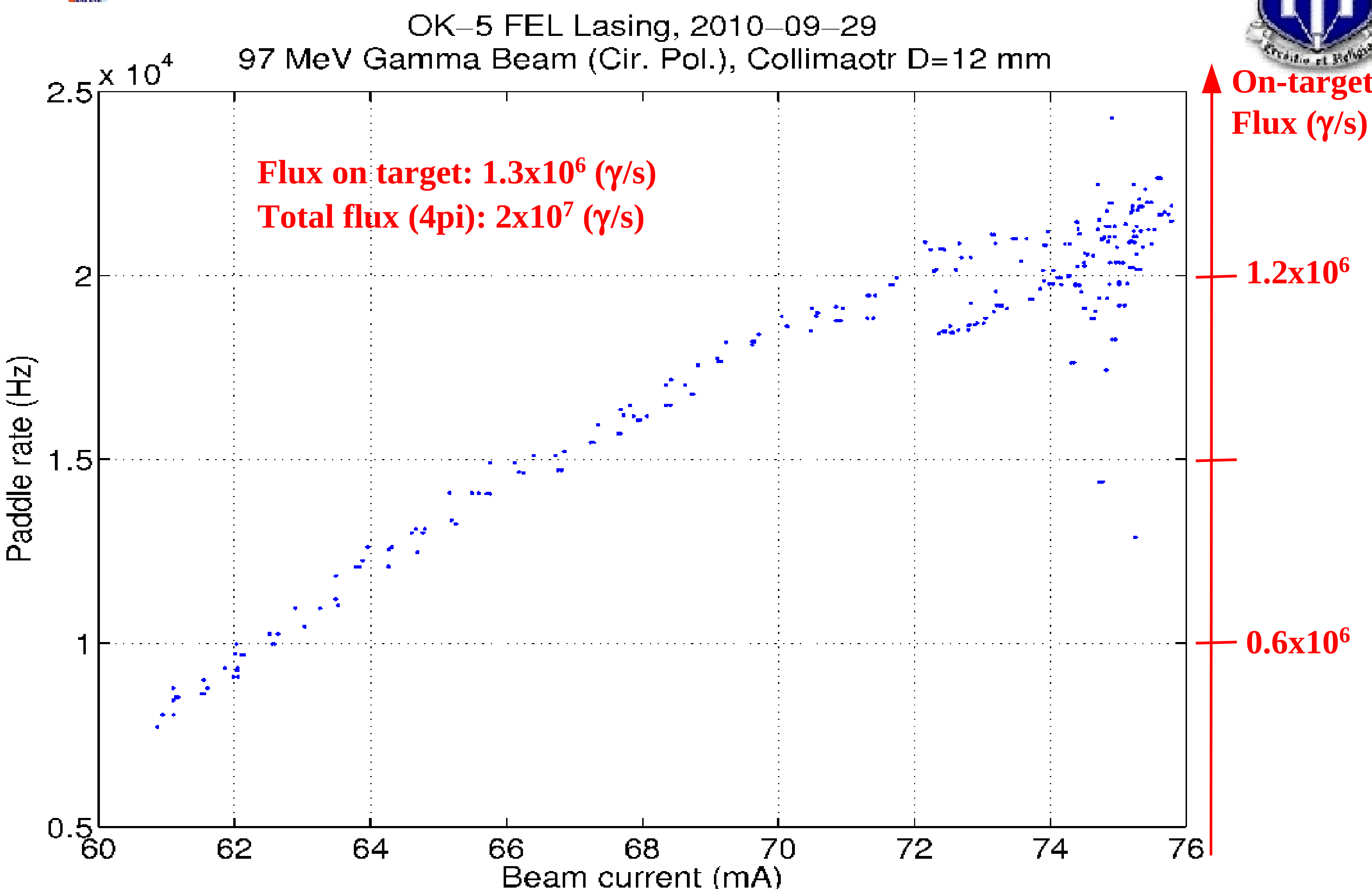
Gamma-ray Beam Spectrua



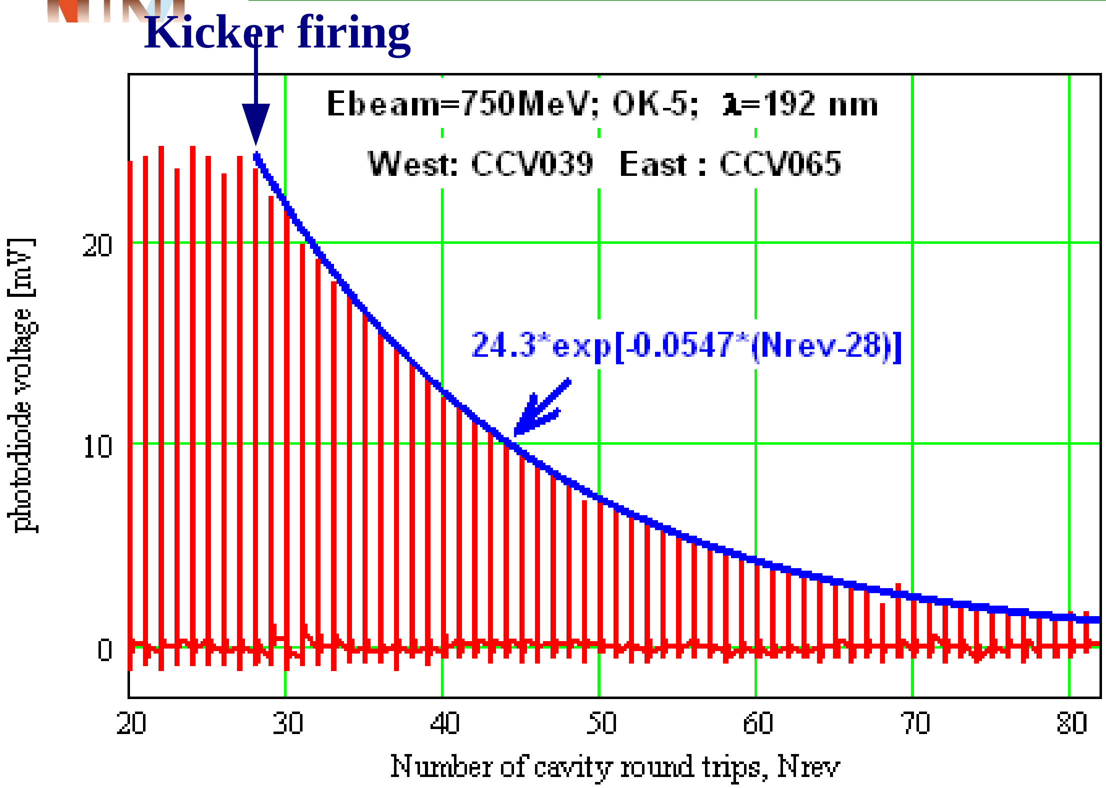


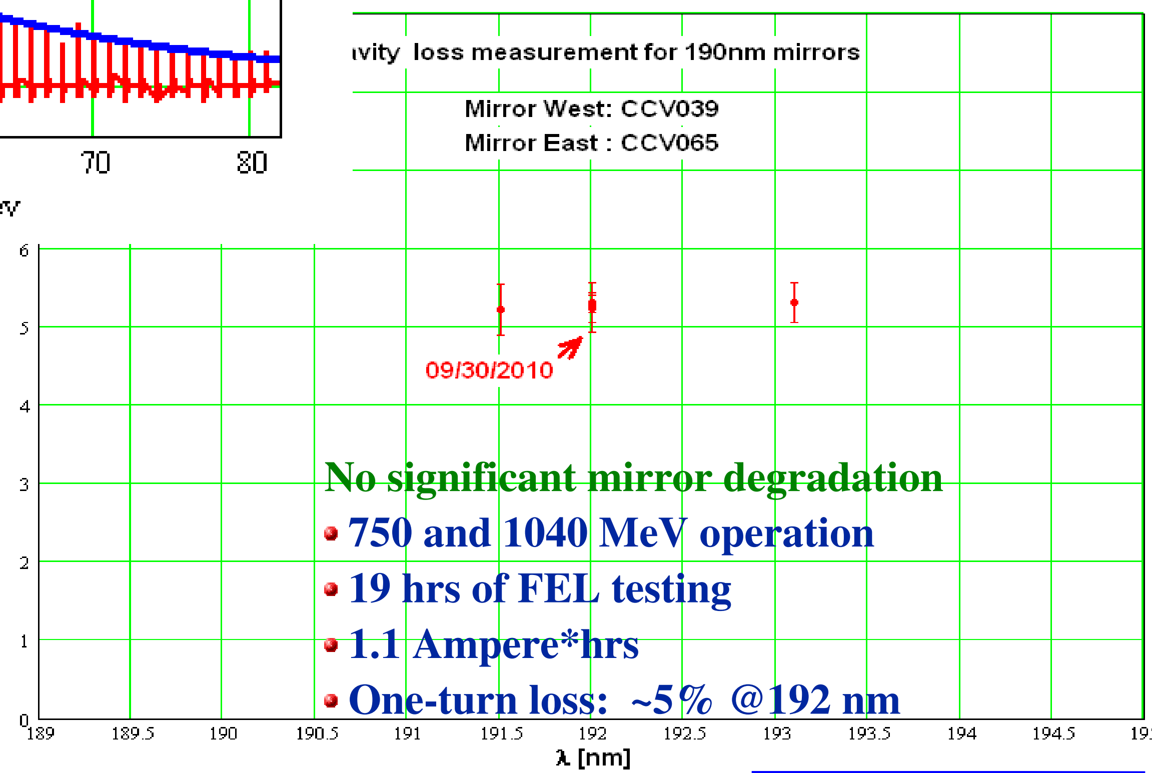
190 nm FEL Lasing

Gamma Beam Flux with Two-bunch Current



190 nm Mirrors: Reflectivity and Transmission

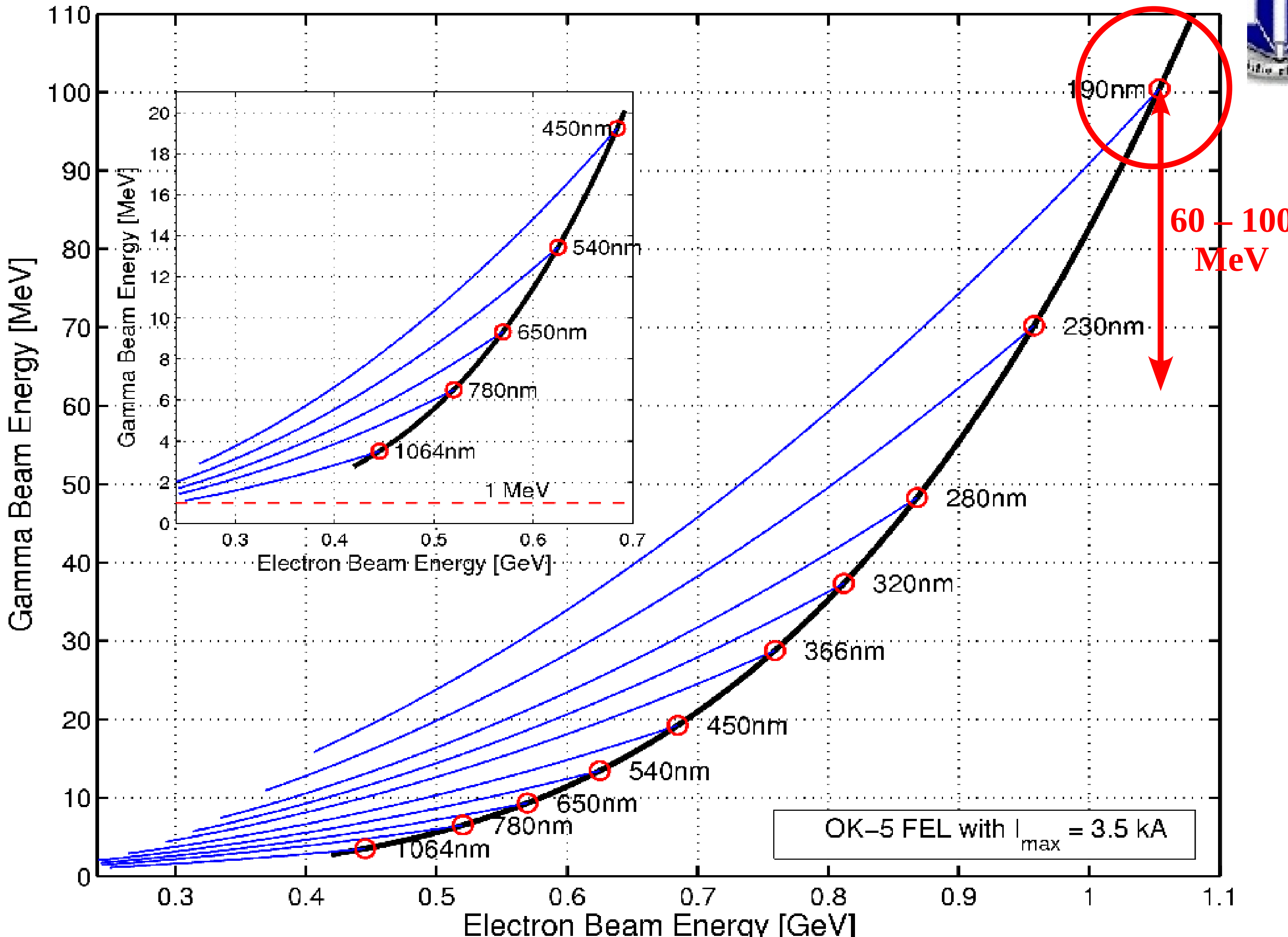




No significant mirror degradation

- **750 and 1040 MeV operation**
- **19 hrs of FEL testing**
- **1.1 Ampere*hrs**
- **One-turn loss: ~5% @192 nm**

Gamma-ray Tuning Range with OK-5 FEL (3.5 kA)



HIGS Capabilities for User Programs in 2011

Parameter	User Beam Capabilities		Comments
E-beam Configuration E-beam current [mA]	Symmetric two-bunch beam 50 - 100		High flux configuration
Gamma-ray Energy [MeV]	1 – 100		with mirrors 1064 to 190 nm Available with existing hardware Extending wiggler current to 3.5 kA
(a) No-loss mode	Total flux [γ/s]	Collimated flux ($\Delta E/E \sim 5\%$) [γ/s]	Both Horizontal and Circular Polarizations
1 – 3 MeV[(a)]	$1 \times 10^8 - 1 \times 10^9$	$6 \times 10^6 - 6 \times 10^7$	
3 – 5 MeV	$6 \times 10^8 - 2 \times 10^9$	$3.6 \times 10^7 - 1.2 \times 10^8$	
5 – 13 MeV	$4 \times 10^8 - 4 \times 10^9$	$2.4 \times 10^7 - 2.4 \times 10^8$	
13 – 20 MeV	$1 \times 10^9 - 2 \times 10^9$	$6 \times 10^7 - 1.2 \times 10^8$	
(b) Loss mode	Total flux [γ/s]	Collimated flux ($\Delta E/E \sim 5\%$) [γ/s]	To extend mirror lifetime, circular polarization is preferred
21 – 54 MeV	$> 2 \times 10^8$ [(b)]	$> 1 \times 10^7$	1st user experiment: March 2011
55 – 65 MeV	$\sim 2 \times 10^8$ [(b)]	$\sim 1 \times 10^7$	
66 – 100 MeV	$1 – 2 \times 10^8$ [(b) (c)]	$0.5 – 1 \times 10^7$	190 nm: Demonstrated: Sep, 2010

(a) With present configuration of OK-5 wigglers separated by 21 m, the circular polarization is about ½ the values here.

(b) The flux in loss mode is mainly limited by injection rate.

(c) Thermal stability of FEL mirror may limit the maximum amount of current can be used in producing FEL lasing, thus flux.

Highest Total Flux (2010): >2x 10^{10} γ/s @ 9 – 11 MeV

H. R. Weller *et al.*, "Research Opportunities at the Upgraded HIγS Facility," Prog. Part. Nucl. Phys. Vol 62, Issue 1, p. 257-303 (2009).

User Research Programs at HIGS Facility

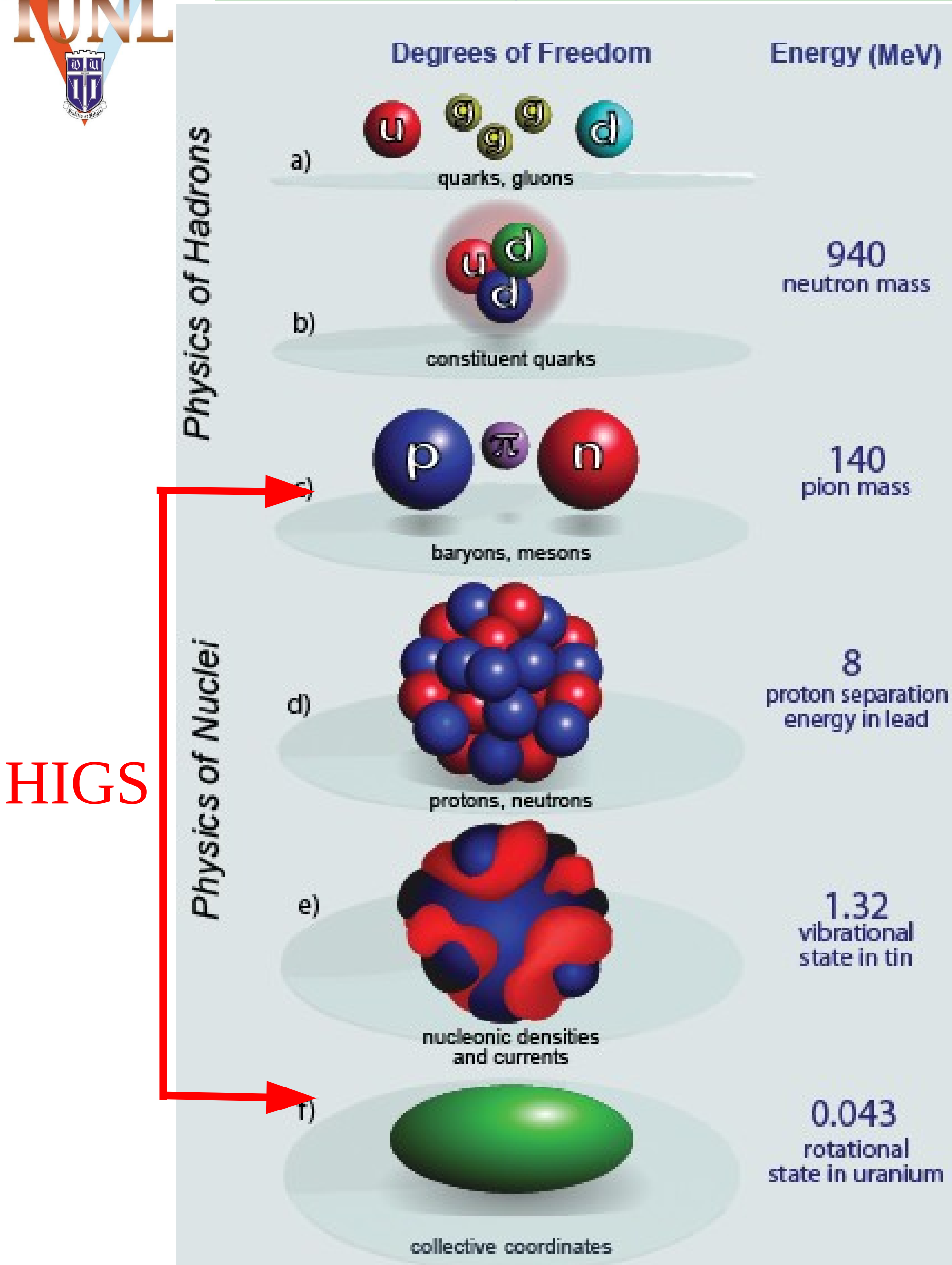
Nuclear Physics Research

Astrophysics Research

Novel Detector Development and Calibration

Industrial and Medical Applications

Nuclear Physics: A Hierarchy of Scales and Energies



Nuclear Structure

Low-energy Electromagnetic Few-Nucleon Physics

Astro-physics

Gerasimov-Drell-Hearn (GDH) Sum Rule

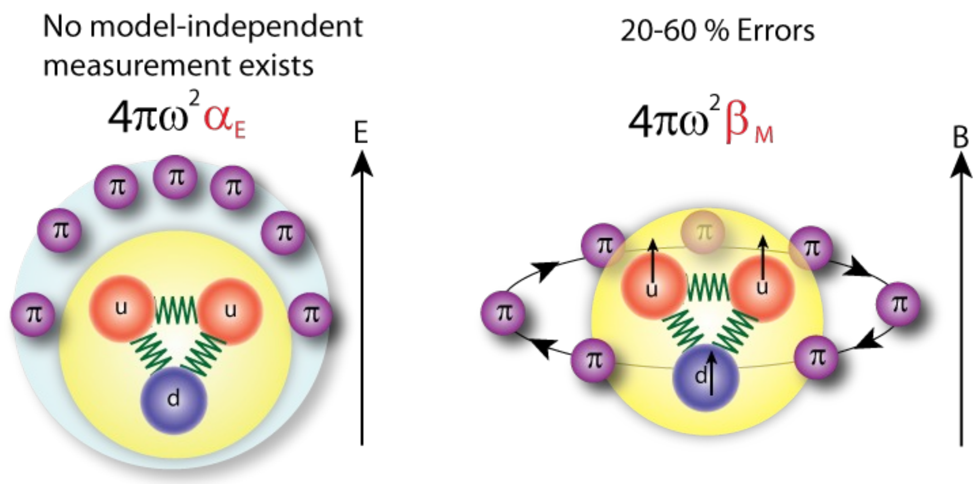
Compton Scattering from Nucleons

Photon-Pion Physics

US DoE Division of Nuclear Physics 2007 Long Range Plan
dnp.nscl.msu.edu/nplinks/

H. R. Weller *et al.*, "Research Opportunities at the Upgraded HIγS Facility," Prog. Part. Nucl. Phys. Vol 62, Issue 1, p. 257-303 (2009).

Compton Scattering to extract polarizabilities of proton and neutron



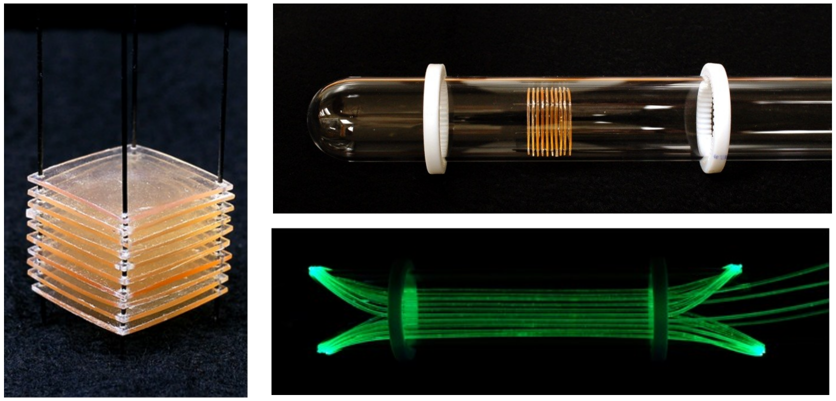
“100 MeV and beyond” Research Program @HIGS

- To measure static, electromagnetic polarizabilities, and spin polarizabilities of nucleons.
- To study chiral dynamics via pion-photo production

“ Effective field theories provide a powerful framework for solving physical problems that are characterized by a natural separation of distance scales. They are particularly important tools in QCD, where the relevant degrees of freedom are quarks and gluons at short distances and hadrons and nuclei at longer distances. Indeed, at energies below the proton mass, the most notable features of QCD are the confinement of quarks and the spontaneous breaking of QCD's chiral symmetry. Chiral perturbation theory is an effective field theory that incorporates both; when applied to mesons it is a mature theory. Perhaps the most striking advances in chiral effective field theory have come in its application to few-nucleon systems. This has yielded precise results for nucleon-nucleon forces and also produced consistent three-nucleon forces. This opens the way for precision analyses of electromagnetic reactions on light nuclei, e.g., the Compton scattering reactions on systems having two or three nucleons that will be explored at the High-Intensity Gamma-Ray Source (HIγS) facility at Duke University. ”

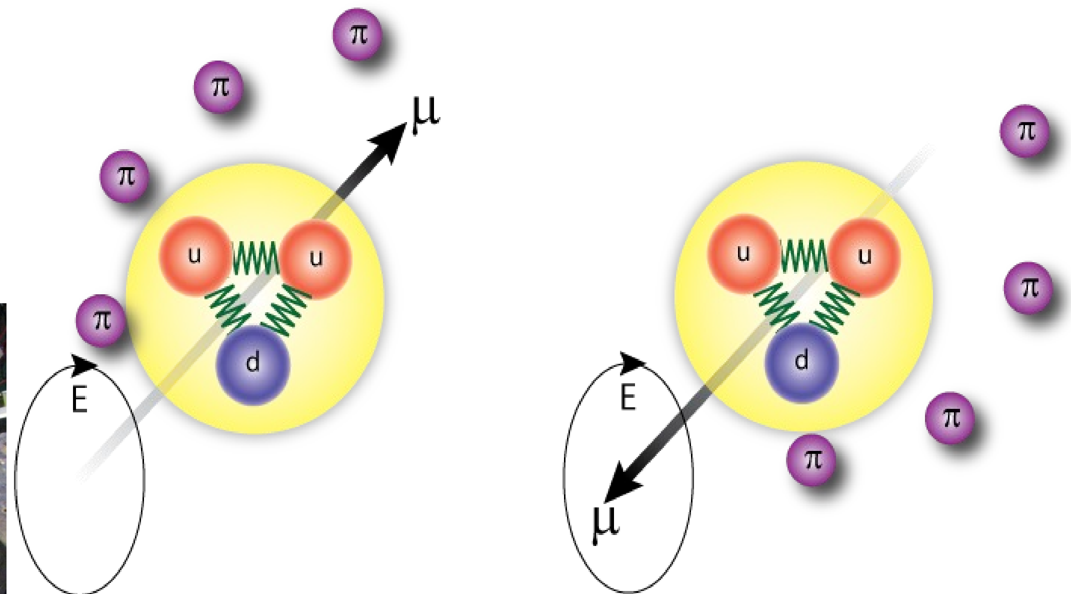
[US Nuclear Physics Long Range Plan: QCD and the Structure of Hadrons, p 18]

Courtesy: Mohammad Ahmed, Henry Weller, Rory Miskimen, Jerry Feldman, Haiyan Gao, Don Crabb, Blaine Norum

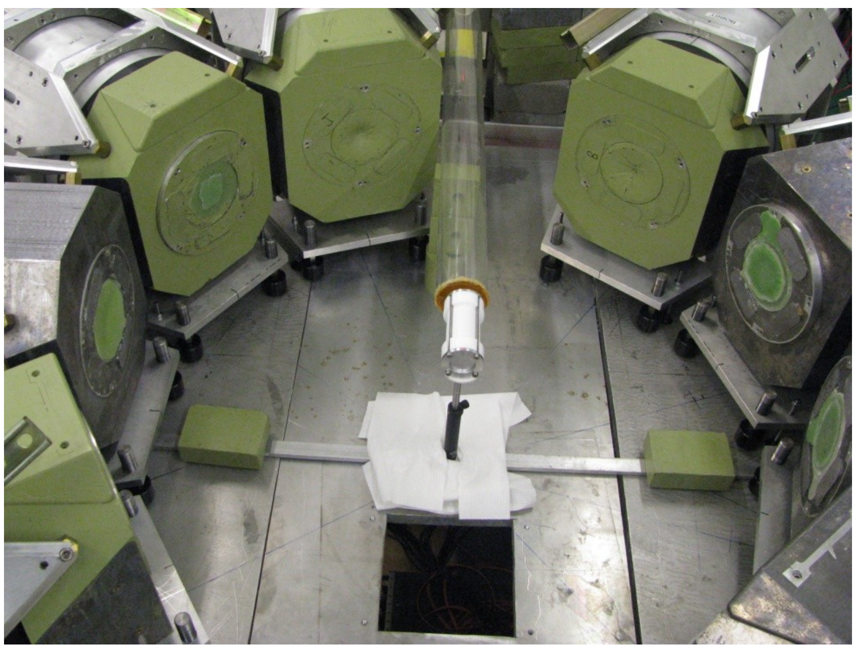


Scintillating Polarized Target

Compton Scattering to extract spin-polarizabilities of proton and neutron
Measurement of the spin-stiffness of the nucleon



No measurements exist of the spin polarizabilities

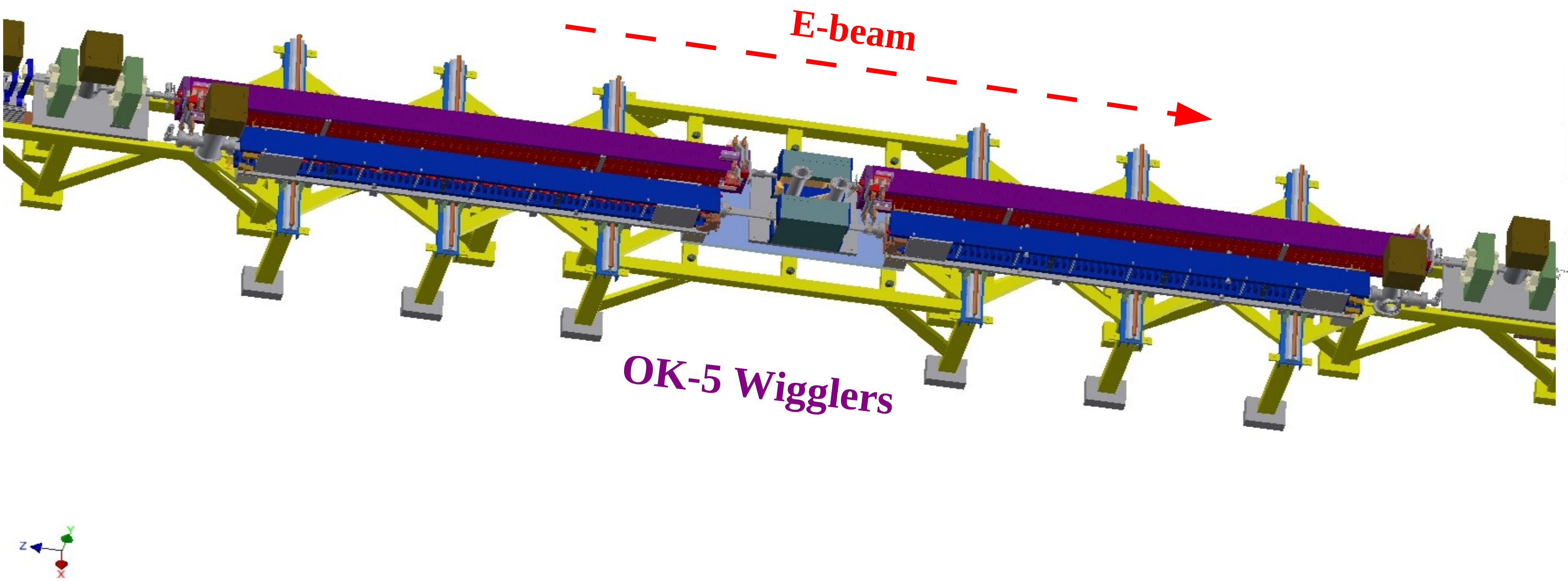


HIGS NaI Detector Array (HINDA)
($2M system)

Courtesy: Mohammad Ahmed, Henry Weller, Rory Miskimen, Jerry Feldman, Haiyan Gao, Don Crabb, Blaine Norum

Switch-yard for OK-4 and OK-5 Wigglers

FEL Lasing: ~170 and 150 nm
HIGS Operation: 100 – 160 MeV operation with OK-5 FEL



Summary

Duke FEL Capabilities

- Operation Range: 1060 nm – 190 nm
- Linear and Circular Polarization
- CW and Pulsed Operation

HIGS Capabilities

- Energy Tuning: 1 - 100 MeV
- Maximum Total Flux: > 2 x 10^{10} γ/s around 10 MeV
- Maximum Spectrum Flux: : ~ 10^{3} γ/s/eV around 5 - 10 MeV
- High Energy Resolution: 0.8% (< = 5 MeV)
- Polarization: linear, circular; switchable polarization

Future Development

- VUV FEL Lasing: ~170nm, ~150 nm
- Higher Gamma-beam Energy: 110 - 160 MeV