Performance and Capabilities of Upgraded High Intensity Gamma-ray Source (HIGS) at Duke University

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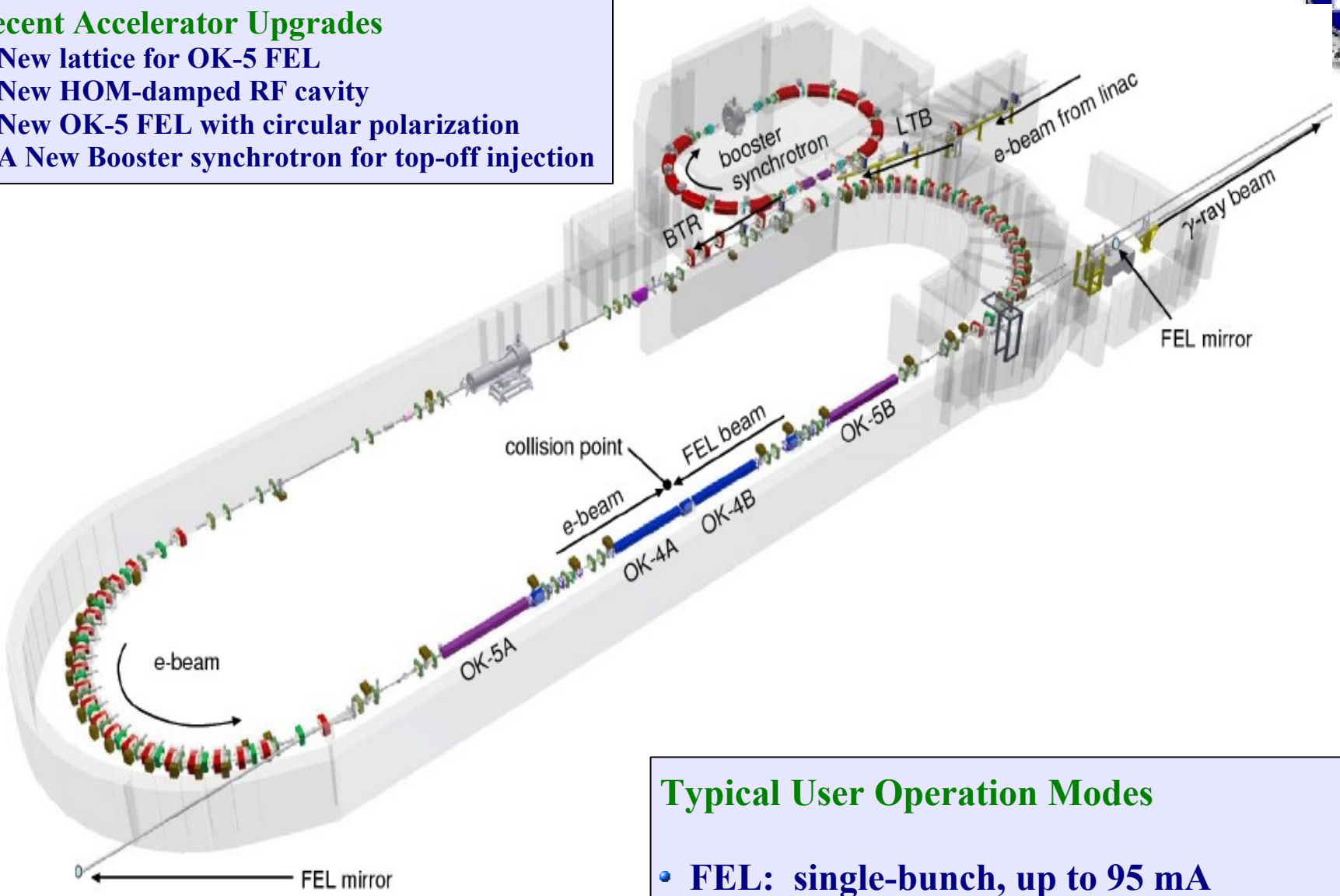
Outline

- **High Intensity Gamma-ray Source (HIGS)**
  - Duke FEL Lab Accelerator Facility Overview
  - HIGS Operation
    - Operation Principle
    - Energy Tuning Range
    - Performance and Capabilities
- **Critical Development for HIGS Since 2007**
  - Full-energy, top-off booster injector
  - Helical OK-5 FEL (two wigglers)
  - Bunch-by-bunch Longitudinal Feedback System
  - In -cavity, Water-cooled Aperture System
- **Future Development for HIGS**
  - Flux Front
  - Energy Front

Layout of the Duke FEL Lab Accelerator Facility

Recent Accelerator Upgrades

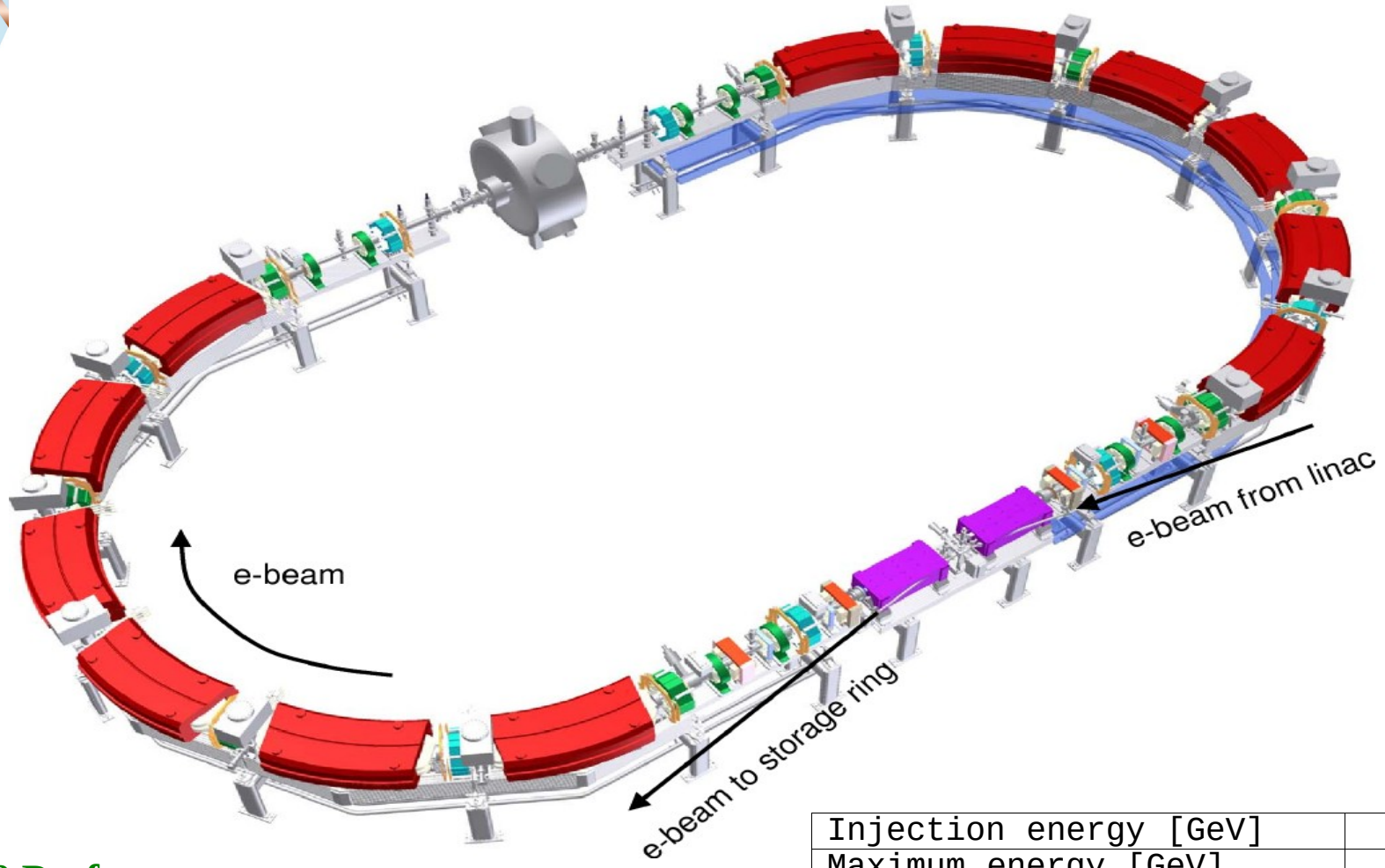
- New lattice for OK-5 FEL
- New HOM-damped RF cavity
- New OK-5 FEL with circular polarization
- A New Booster synchrotron for top-off injection



Typical User Operation Modes

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

Full Energy, Top-off Booster Injector (0.18 – 1.2 GeV)

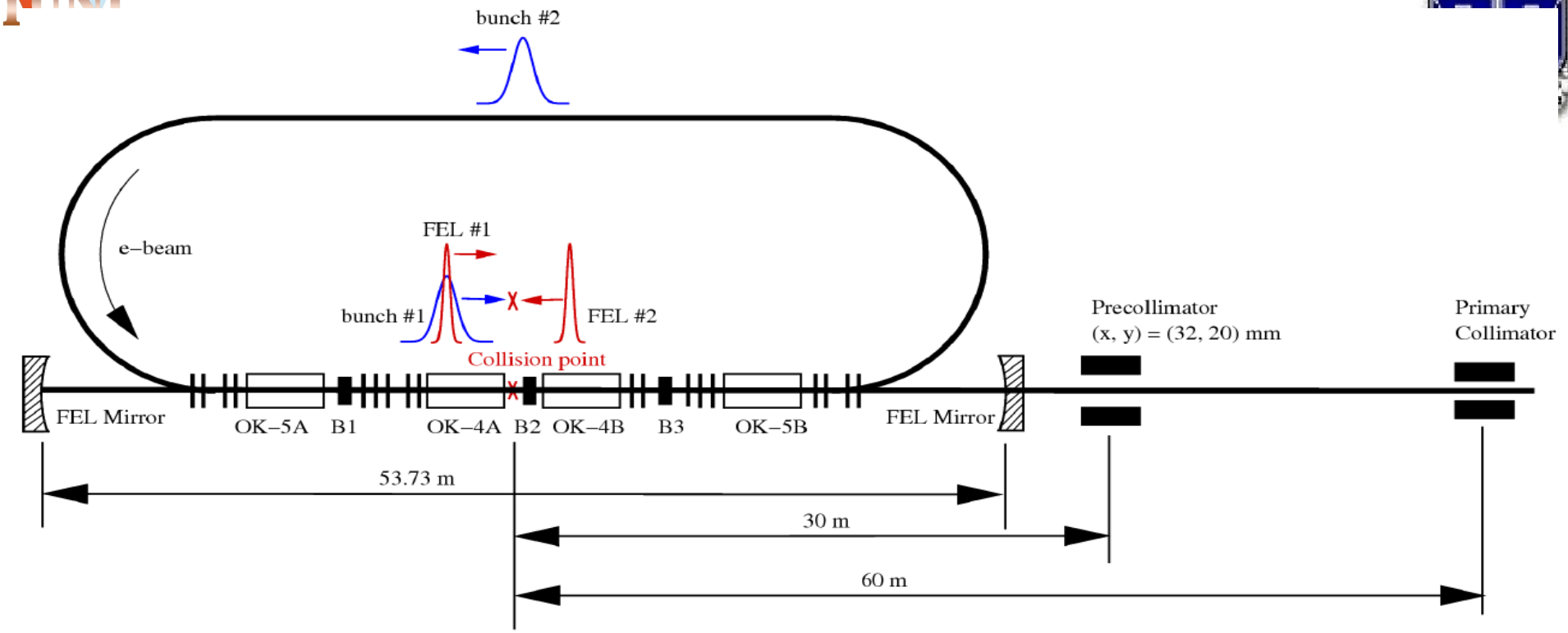


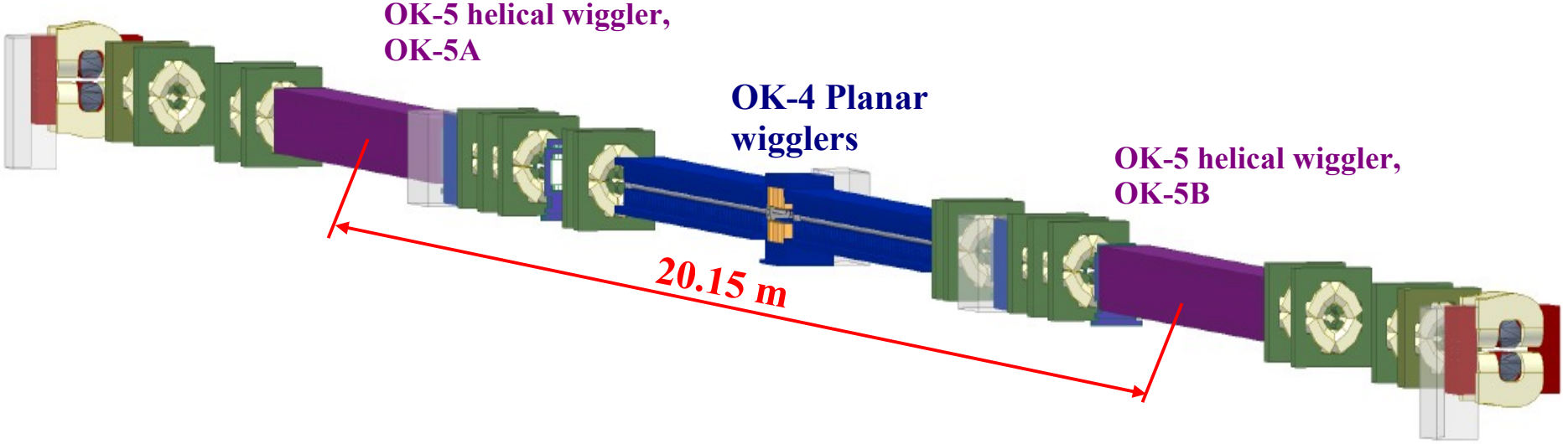
Injection energy [GeV]	0.18-0.27
Maximum energy [GeV]	1.2
Circumference [m]	31.902
RF frequency [MHz]	178.55
Harmonic number	19
Operation cycle [sec]	1.3 - 2.5
Emittance e_x, e_y [nm·rad]	350/ 15
Betatron tunes Q_x/Q_y	2.43/0.46
Momentum compaction	0.153

2009 Performance

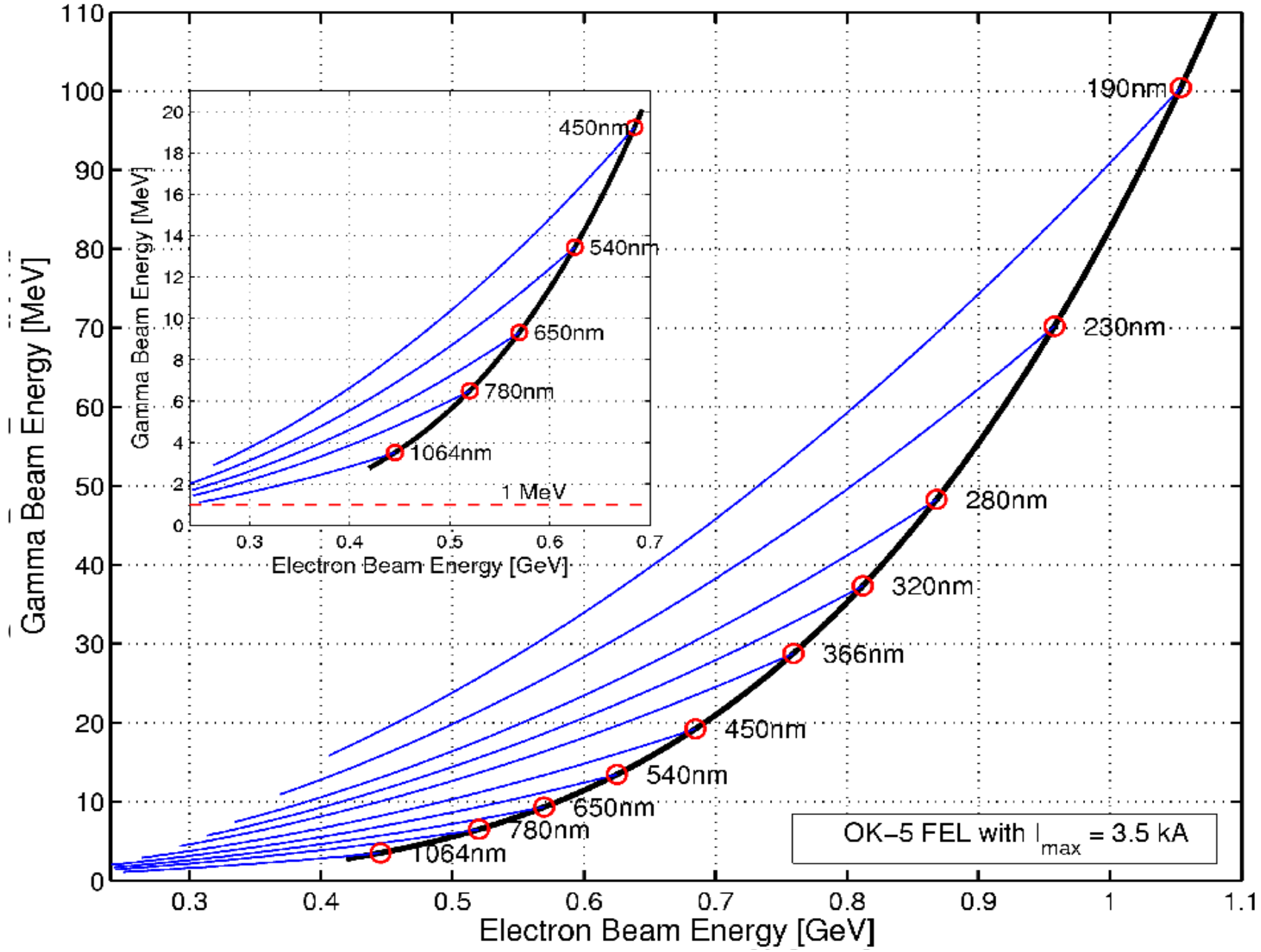
- Injection: 180 - 270 MeV
- Extraction: 0.18 - 1.2 GeV
- Cycle time: 1.3 - 2.5 sec (one or two bunches)
- Charge into storage ring: 0.05 - 0.12 nC/sec
- Recent: 6-bunch injection: 0.2 - 0.25 nC/sec

Operation Principle





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



HIGS Capabilities for User Programs in 2009

Parameter	Value		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 (ΔE/E=3%) [γ/s]	Both Horizontal and Circular Polarizations
1 – 3 MeV[(a)]	$1 \times 10^8 - 1 \times 10^9$	$5 \times 10^6 - 5 \times 10^7$	
3 – 5 MeV	$6 \times 10^8 - 2 \times 10^9$	$3 \times 10^7 - 1 \times 10^8$	
5 – 10 MeV	$4 \times 10^8 - 2 \times 10^9$	$2 \times 10^7 - 1 \times 10^8$	
10 – 20 MeV	$1 \times 10^9 - 2 \times 10^9$	$5 \times 10^7 - 1 \times 10^8$	
(b) Loss mode	Total flux [γ/s]	Collimated flux (ΔE/E~3%) [γ/s]	To extend mirror lifetime, circular polarization is preferred
21 – 45 MeV	$> 2 \times 10^8$ [(b)]	$> 1 \times 10^7$	
45 – 65 MeV	$\sim 2 \times 10^8$ [(b)]	$\sim 1 \times 10^7$	240 nm mirrors and wiggler @3.5 kA
66 – 100 MeV	$1 – 2 \times 10^8$ [(b)] [(c)]	$0.5 – 1 \times 10^7$	190 nm mirrors and wiggler @3.5 kA

(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.

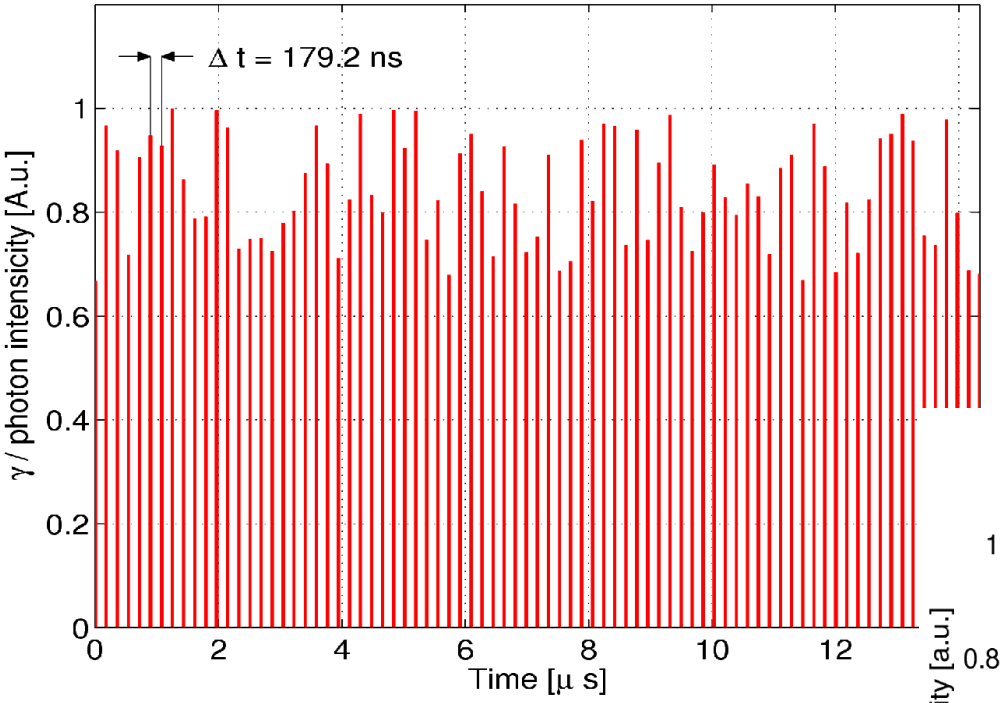
Highest Flux (2009): ~ 10^{10} γ/s @ 11 MeV

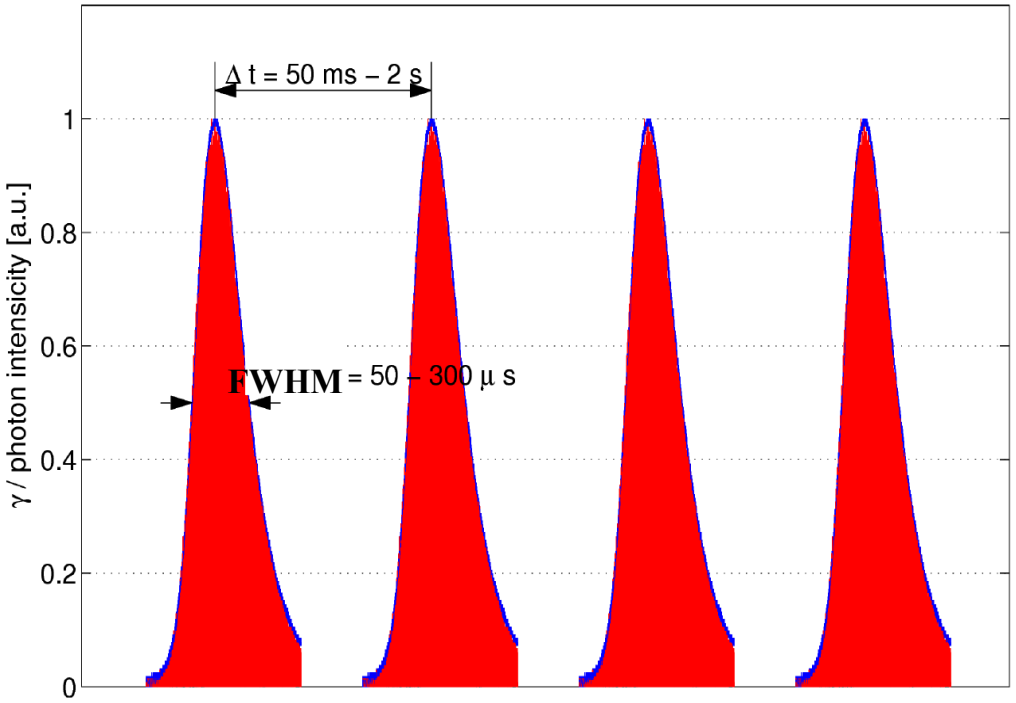
H. R. Weller *et al.*, "Research Opportunities at the Upgraded HIγS Facility," Prog. Part. Nucl. Phys. Vol 62, Issue 1, p. 257-303 (2009).

Operation Modes of HIGS

Operation Modes of HIGS

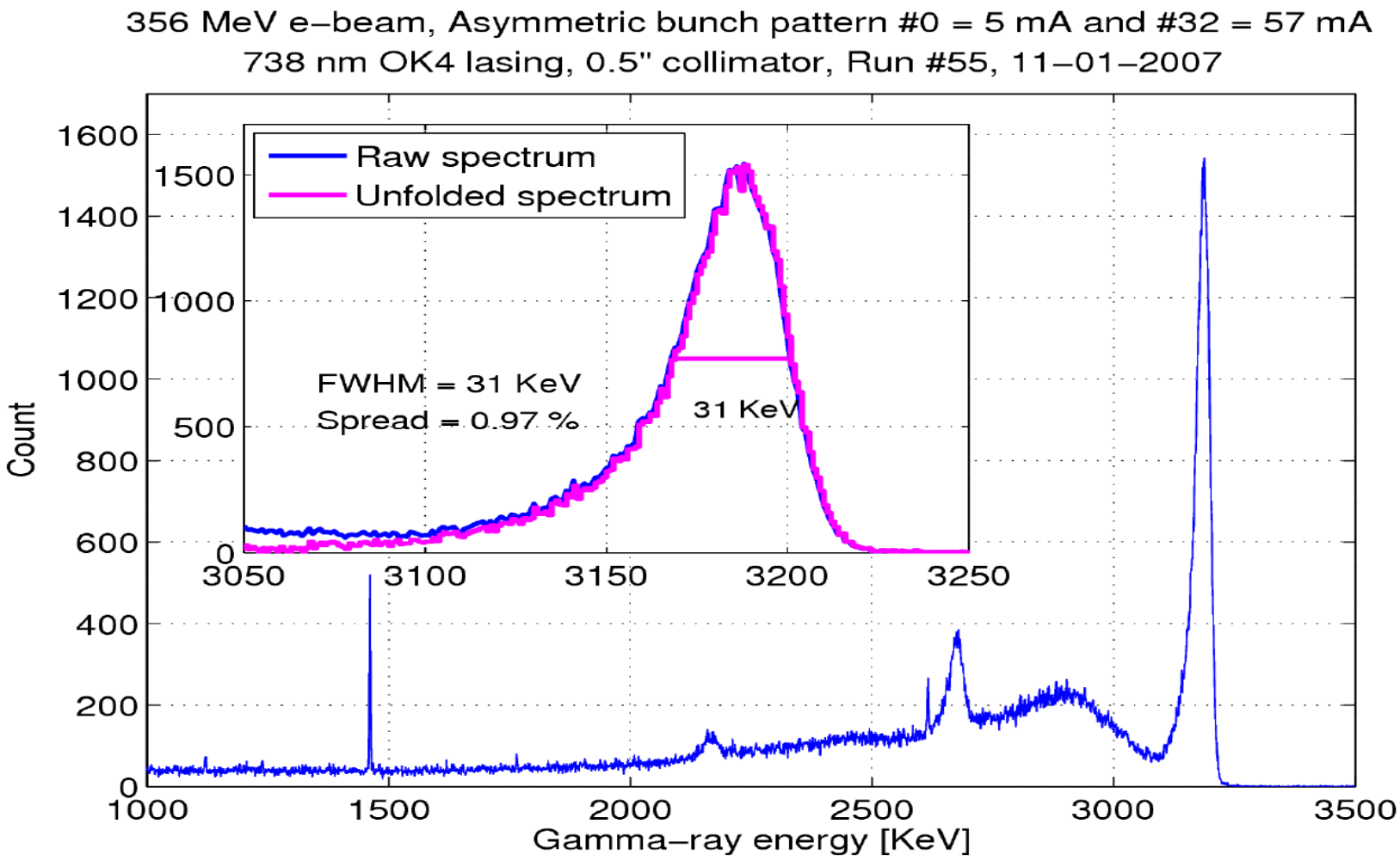
- Qusi-CW operation vs Pulsed
- High-flux vs high energy resolution





High Energy-Resolution Operation

Asymmetric Bunch Pattern: one large (lasing) and one small (non-lasing)



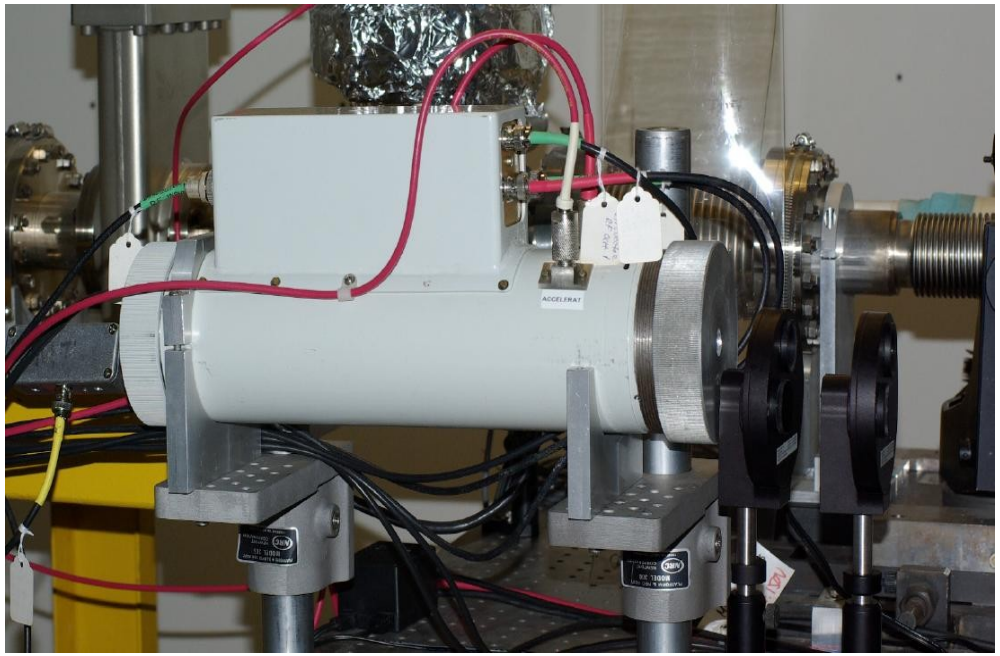
Improving stability of gamma energy resolution and increase flux

- Develop a reliable way to measure bunch pattern, and
- An automatic injection scheme to maintain charge distribution

High Resolution with Asymmetric Two-bunch Operation

Beam Diagnostics

- Live Spectrum Monitor
- Live bunch length monitors



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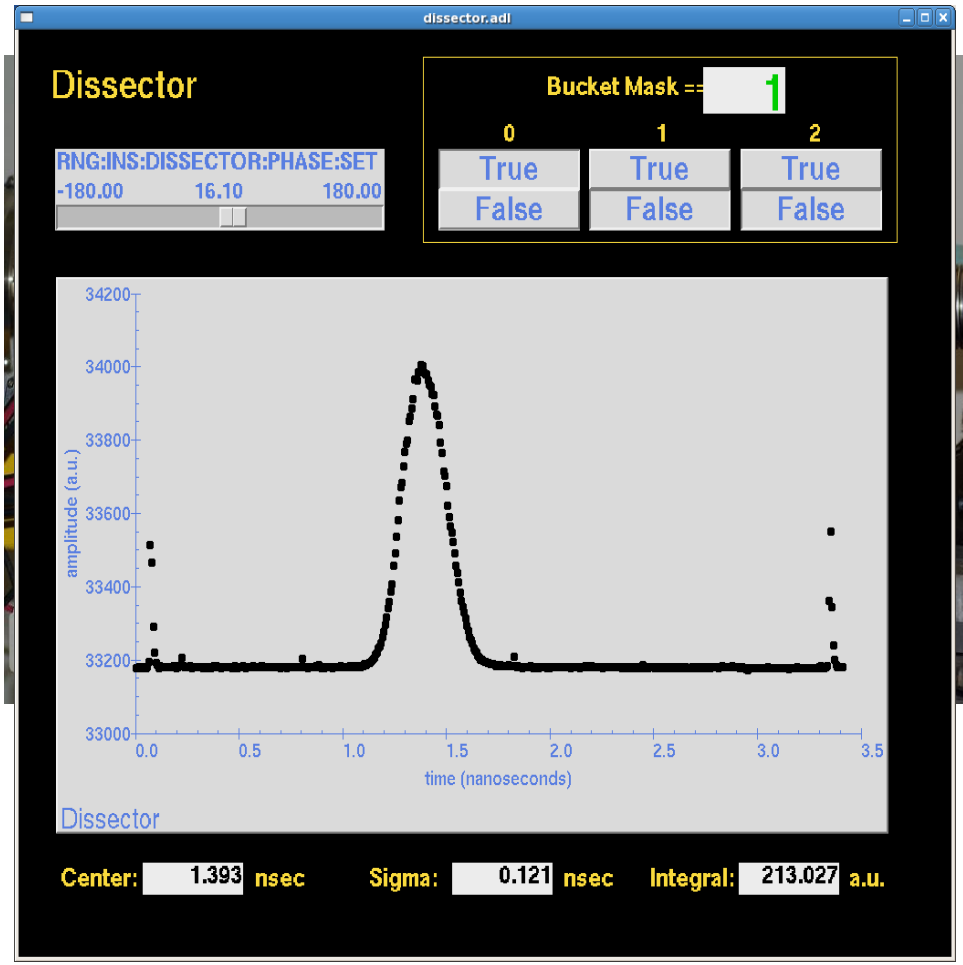

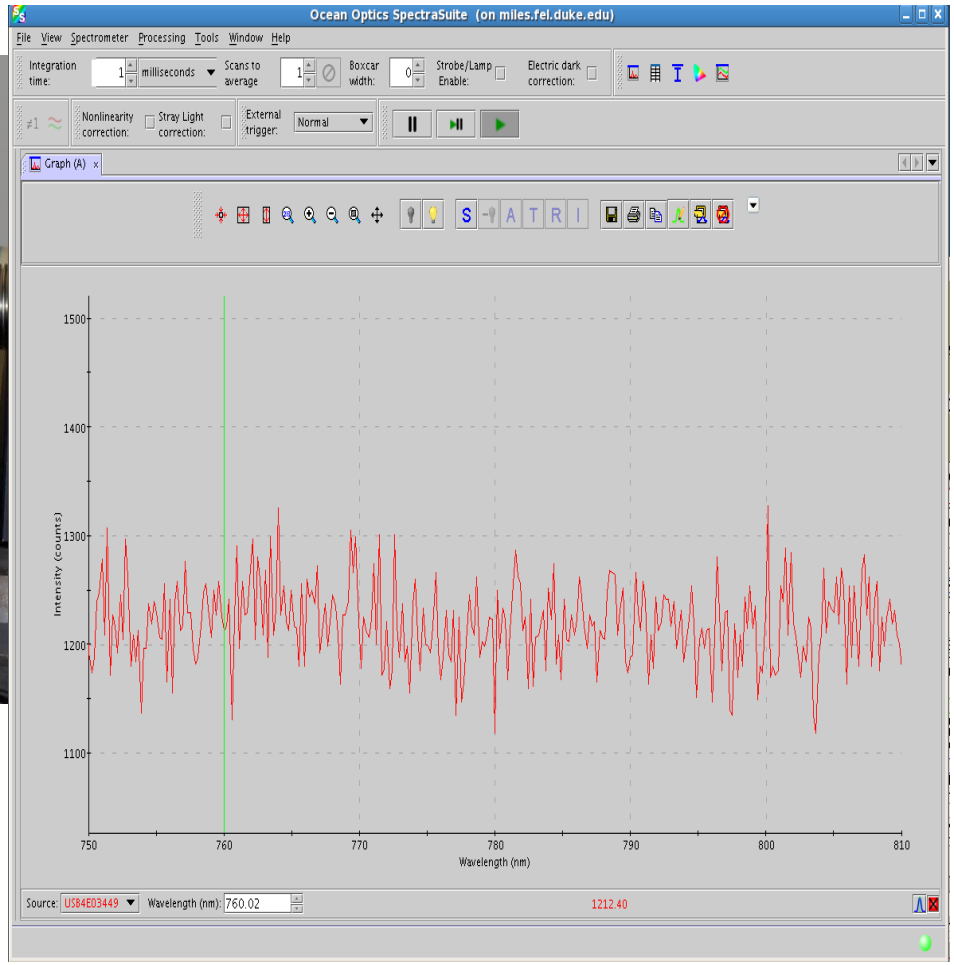

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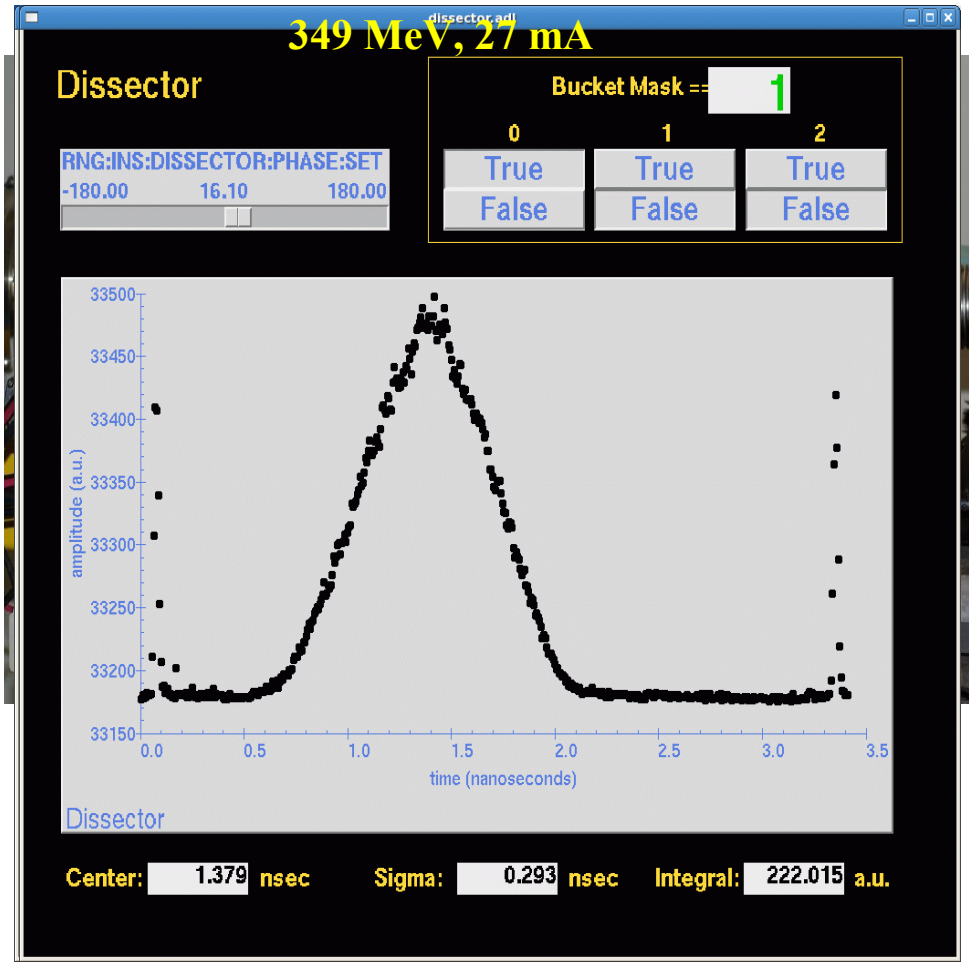
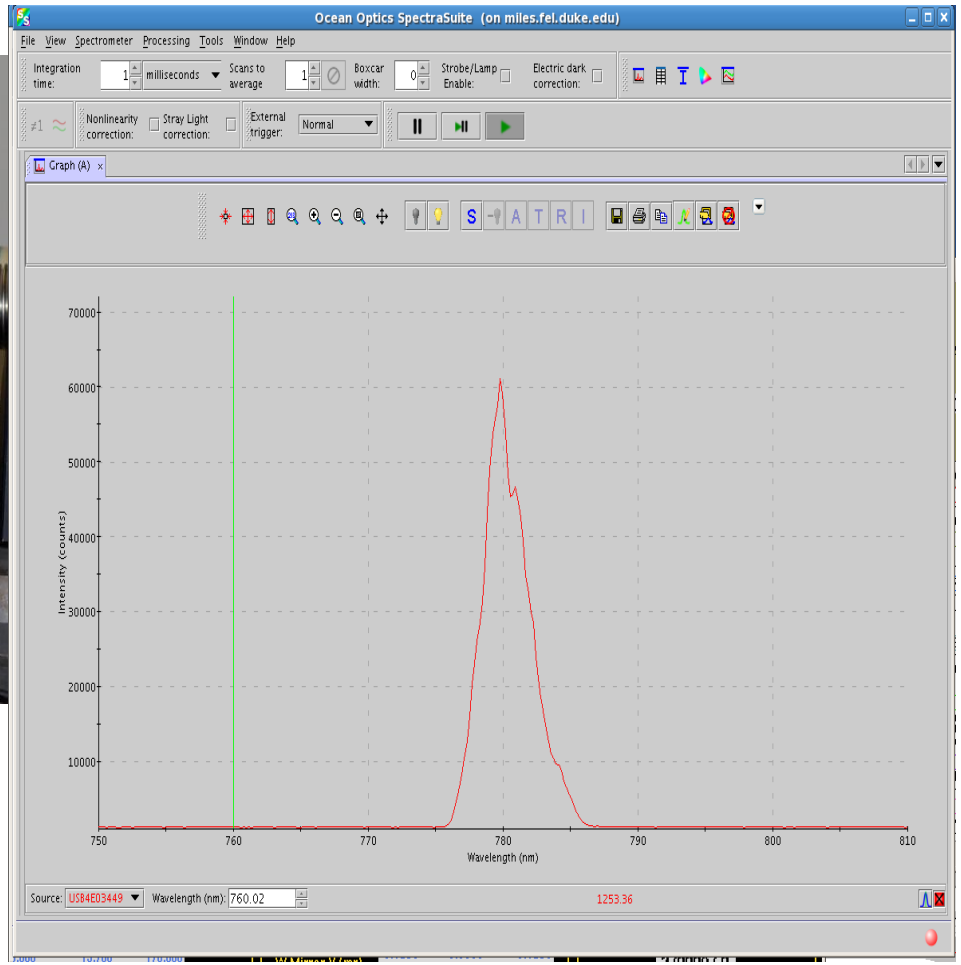
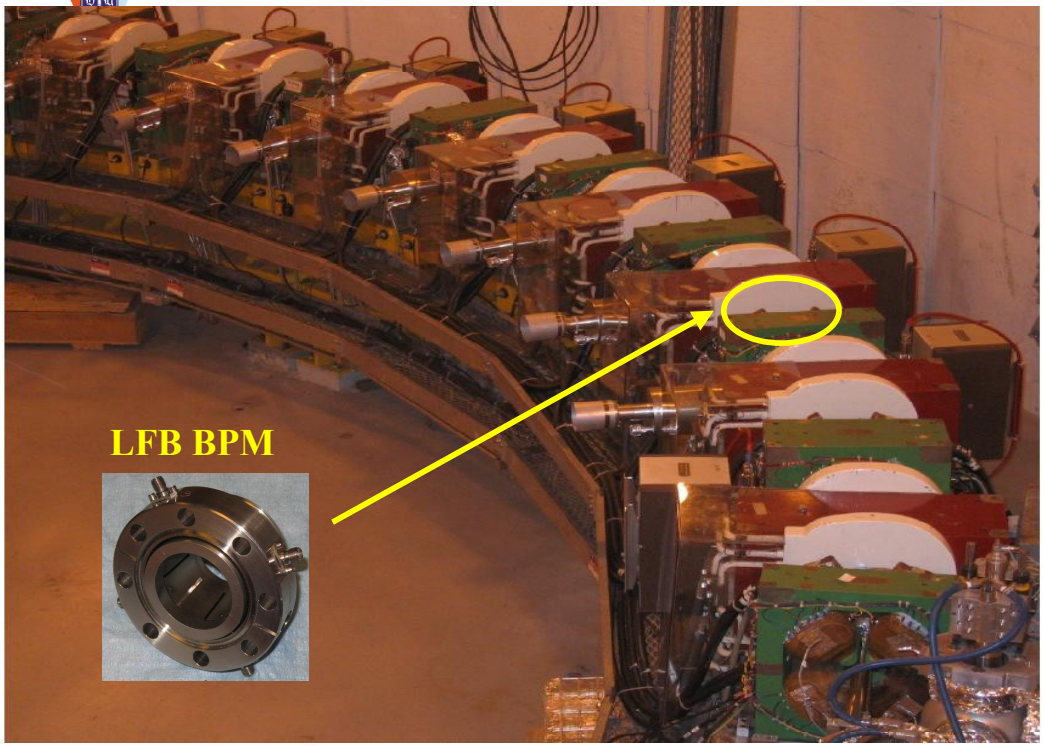
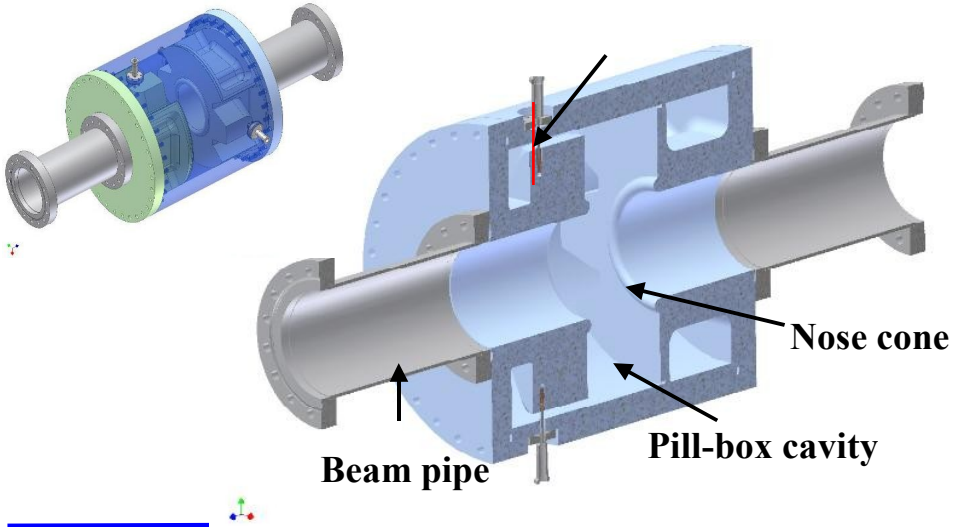




Bunch-by-bunch Longitudinal Feedback

Providing bunch-by-bunch damping of longitudinal instabilities



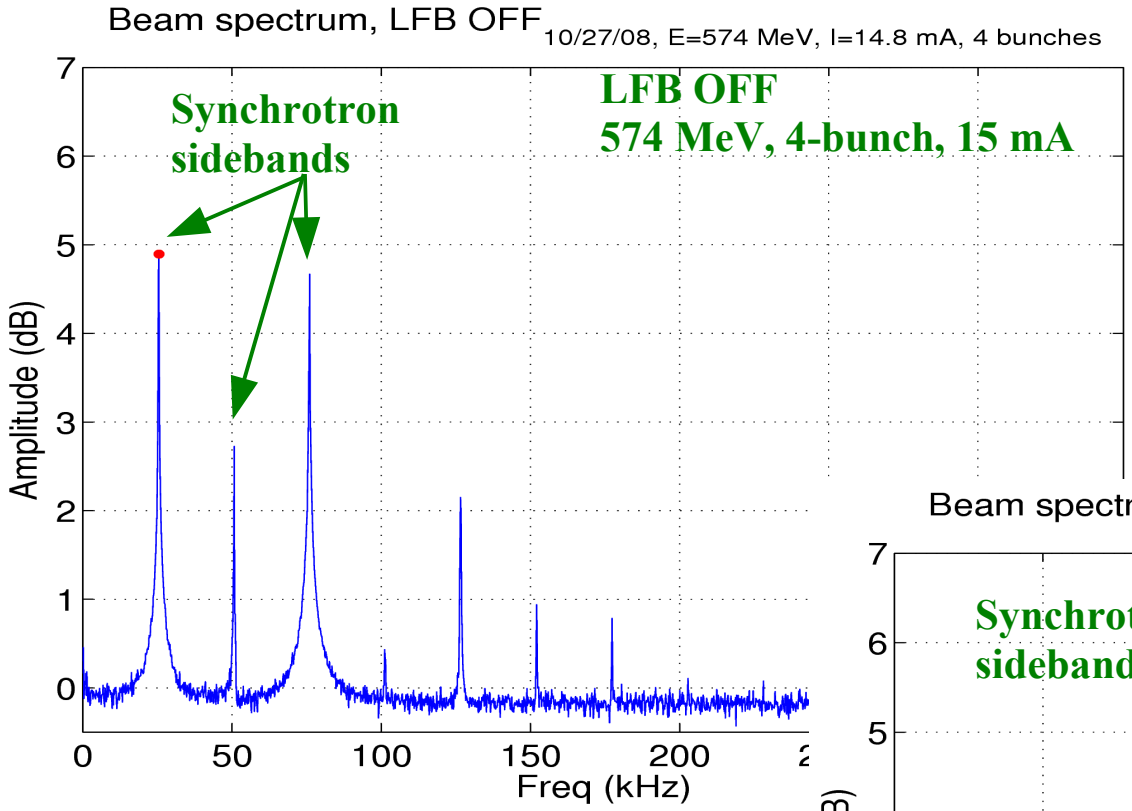


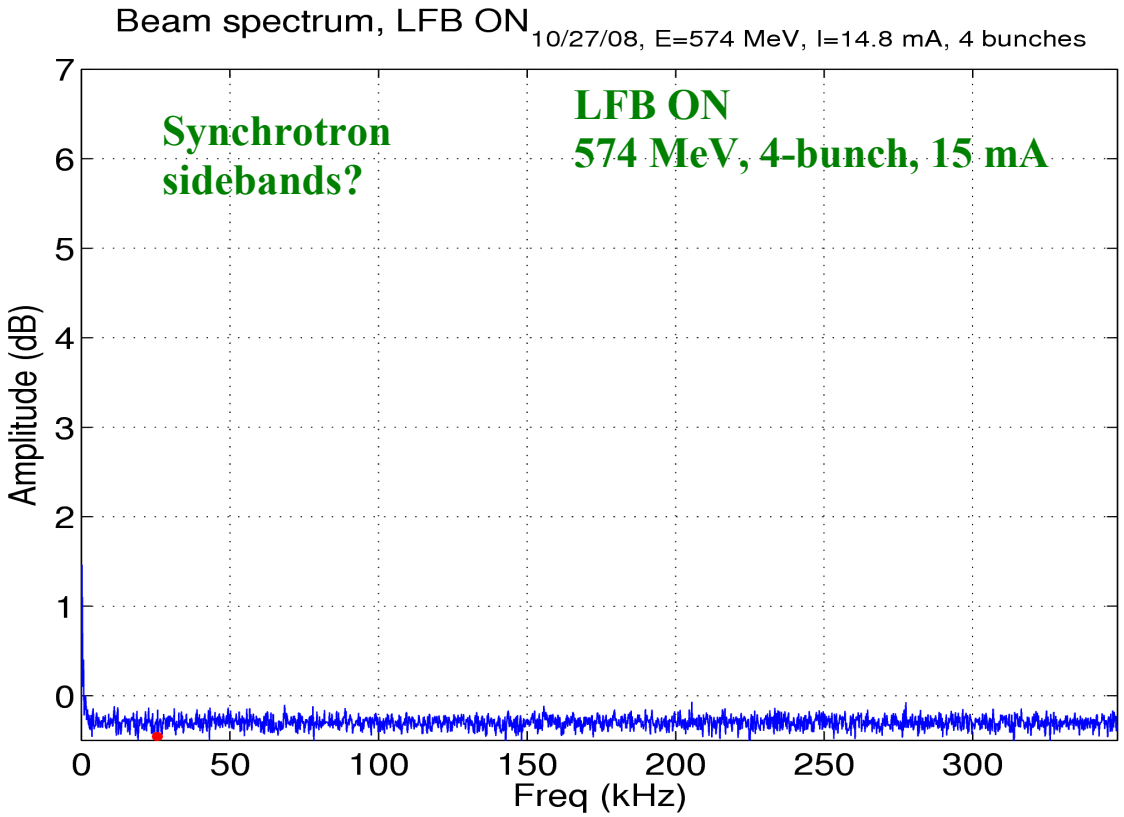
Commissioned for User Operation (Oct., 2008)

Part of Ph.D. thesis work of Wenzhong Wu

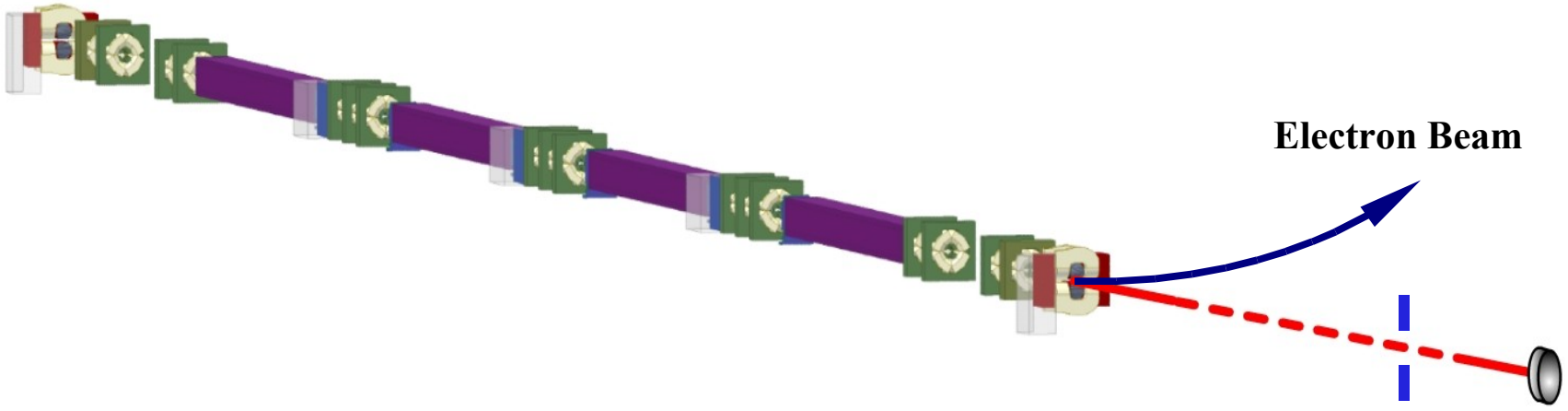
Nose cone

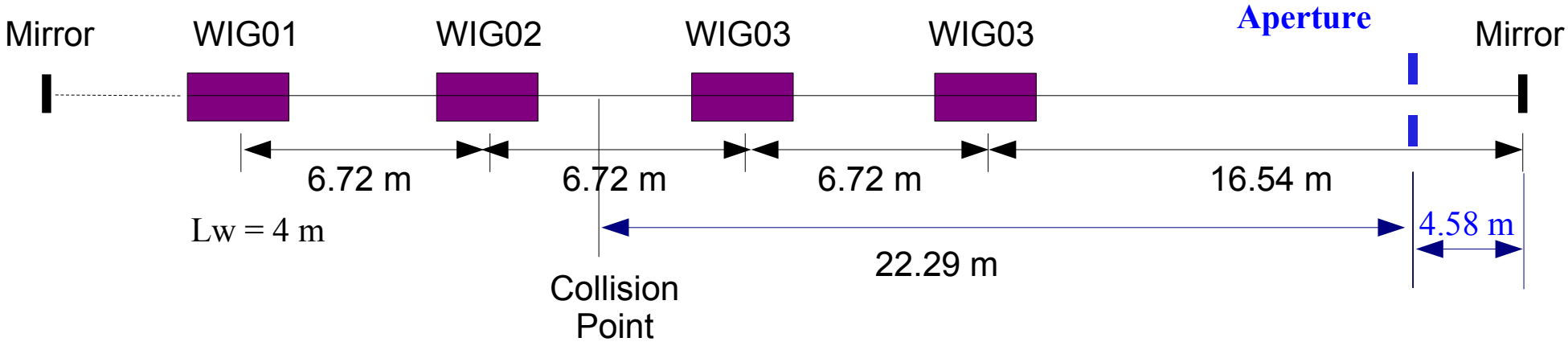
LFB Stabilizing Longitudinal Motion





In-cavity Aperture System for High Current Operation

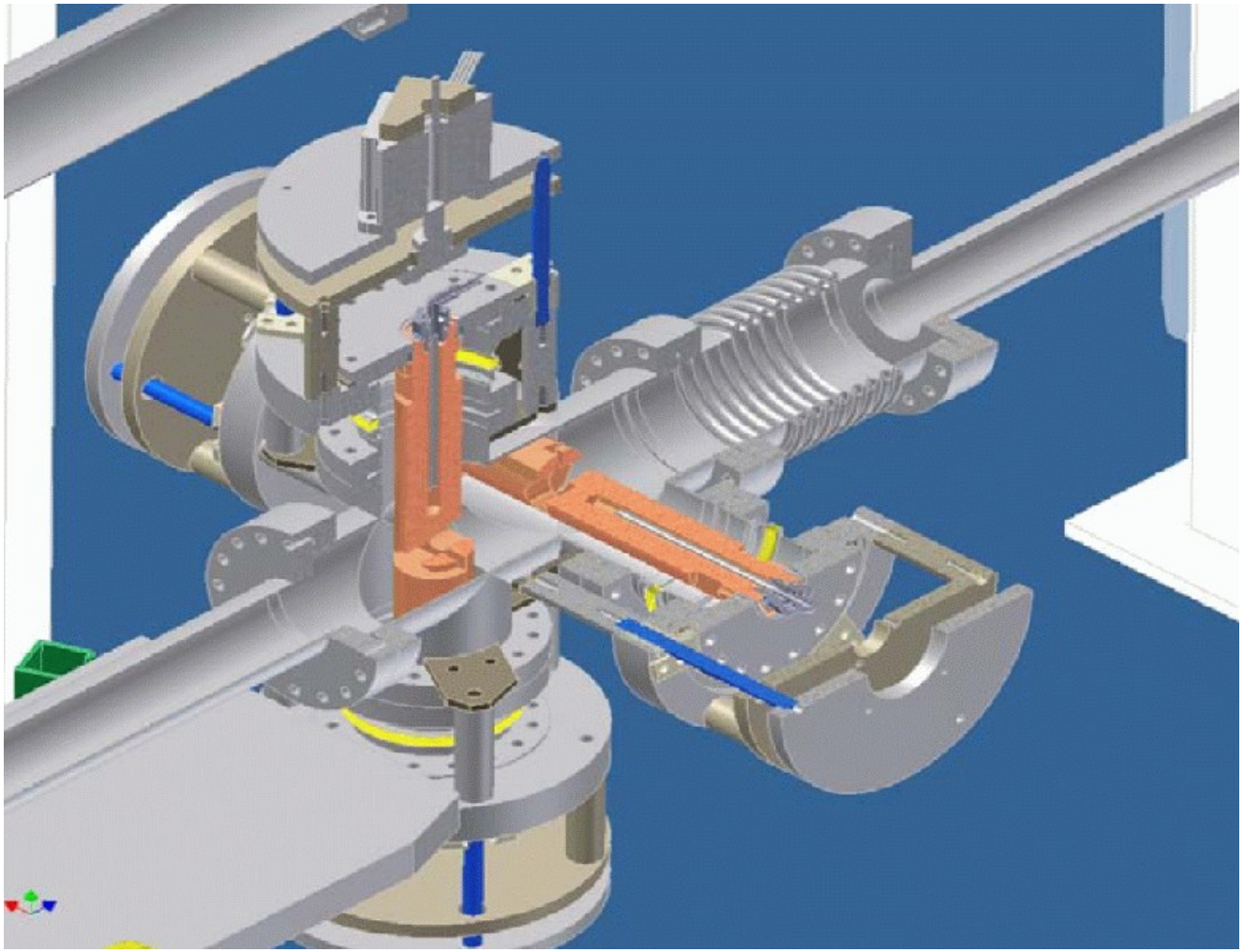




In-Cavity, Water-cooled Apertures

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

Harmonic Power Reduction: about one order of magnitude



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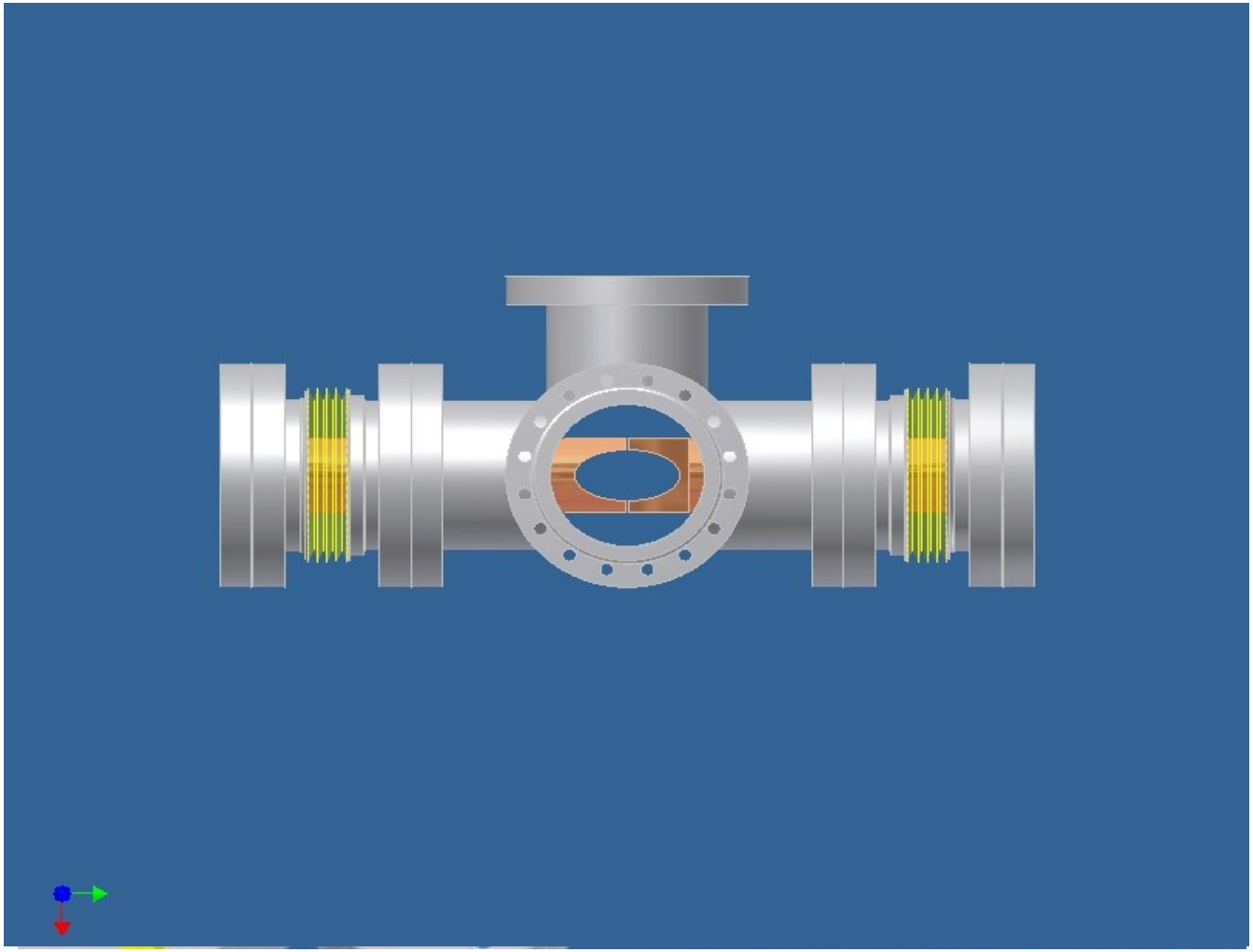

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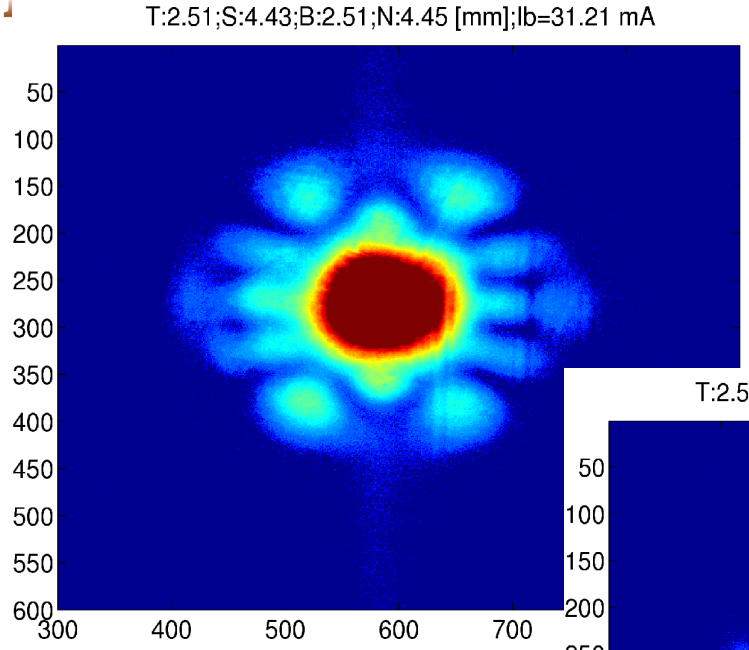
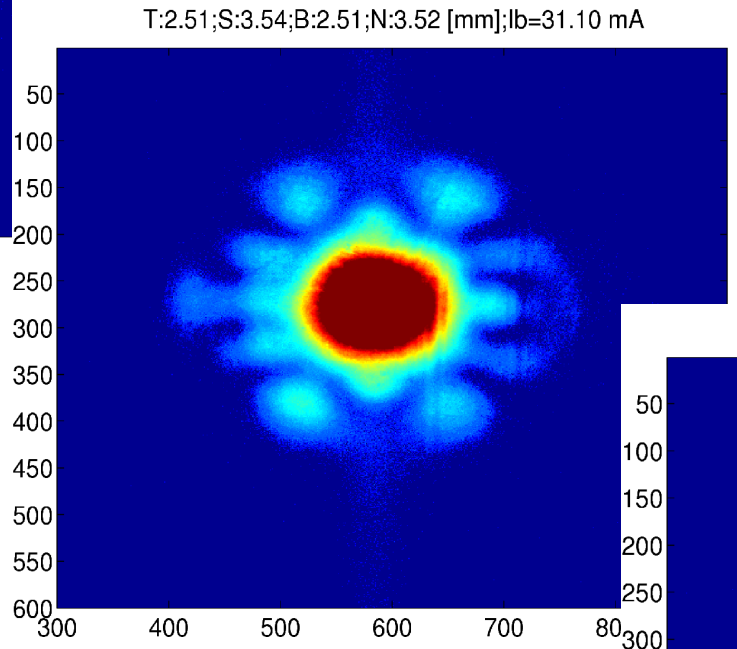
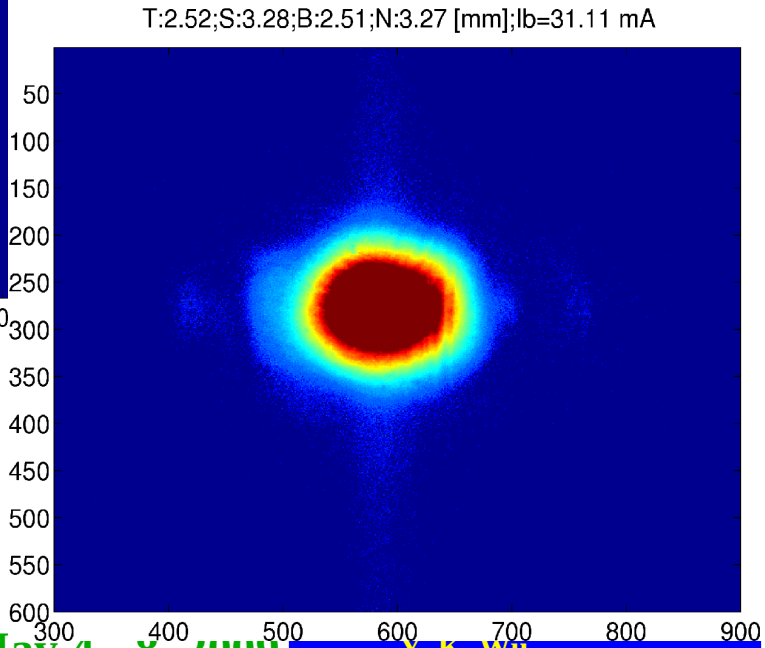
Correcting Mirror Deformation

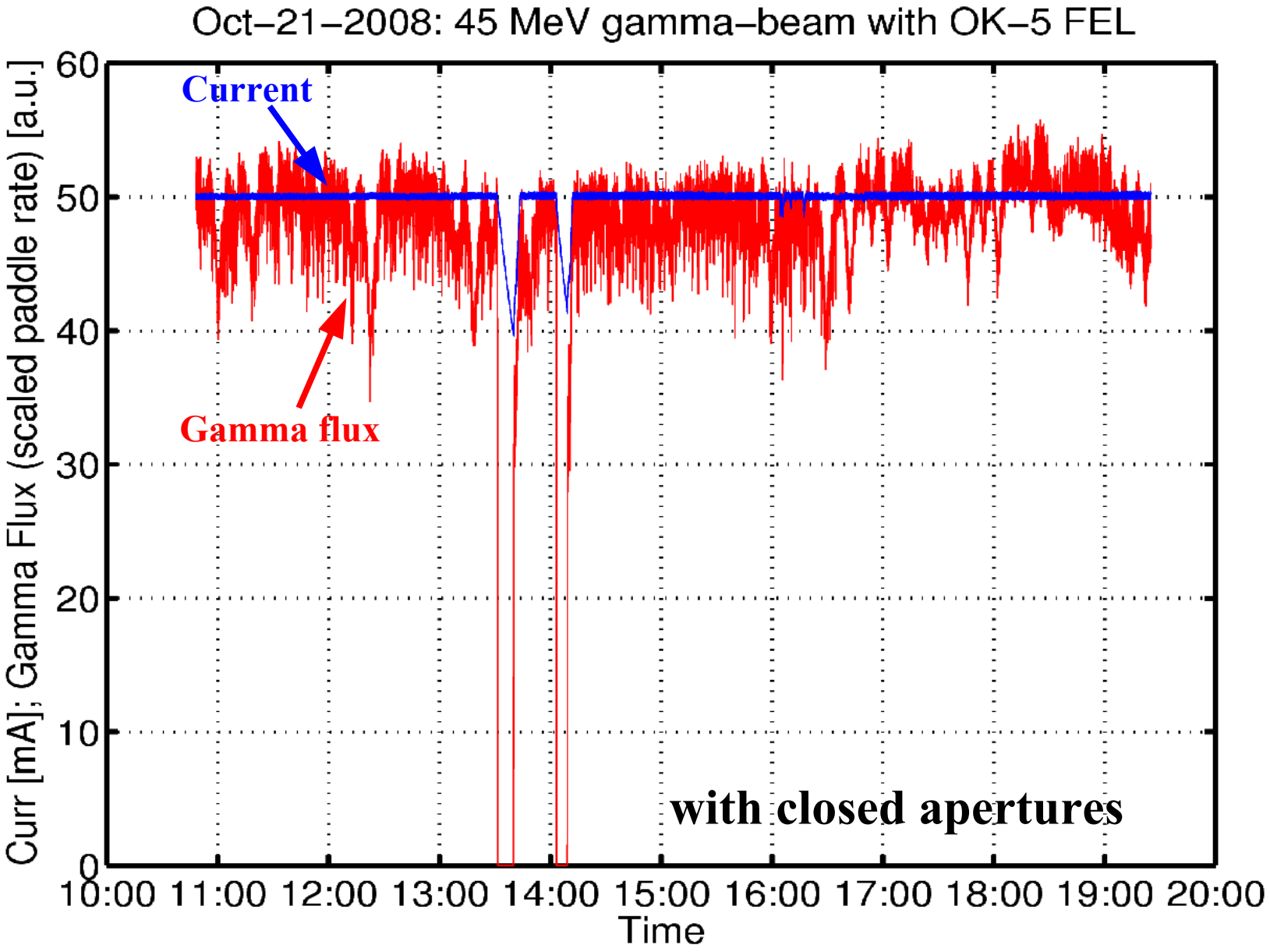
45 MeV Setup with OK-5 FEL







Stability of Gamma Operation in Electron Loss Mode



HIγS Developments and Enhancements (2009 -2011)

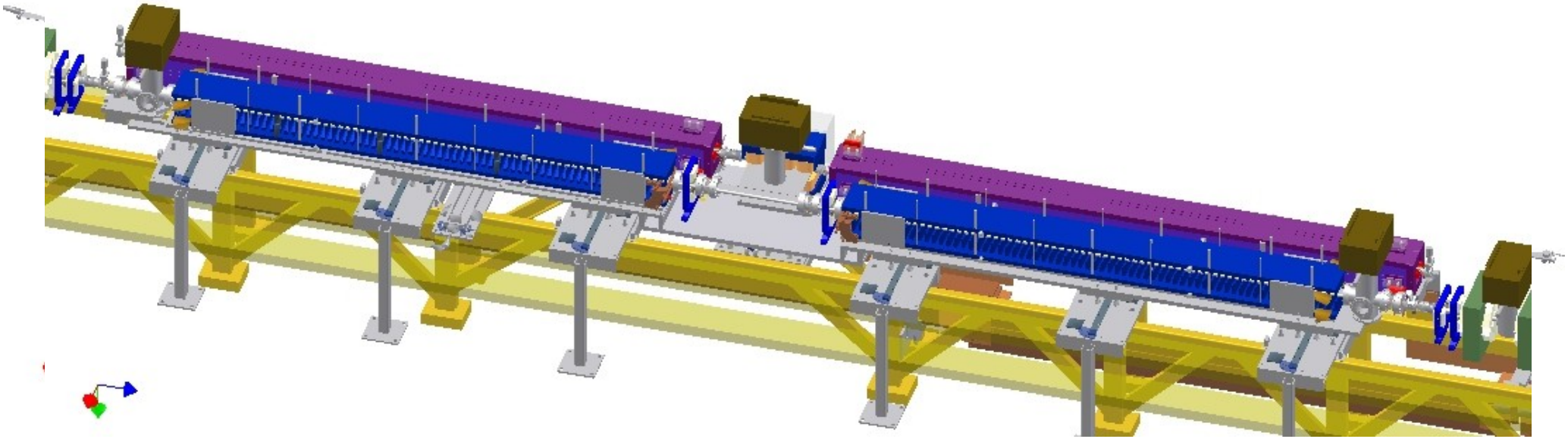
- **Flux Front (1 – 20 MeV)**
  - ***Higher Flux with Linear and Circular Polarization***
  - ***Improved High-resolution Operation***

- **Energy Front**
  - ***Pion threshold energy of 150 – 160 MeV***

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

Photon-pion physics

- 150 – 160 MeV operation with the OK-5 FEL lasing around 150 nm



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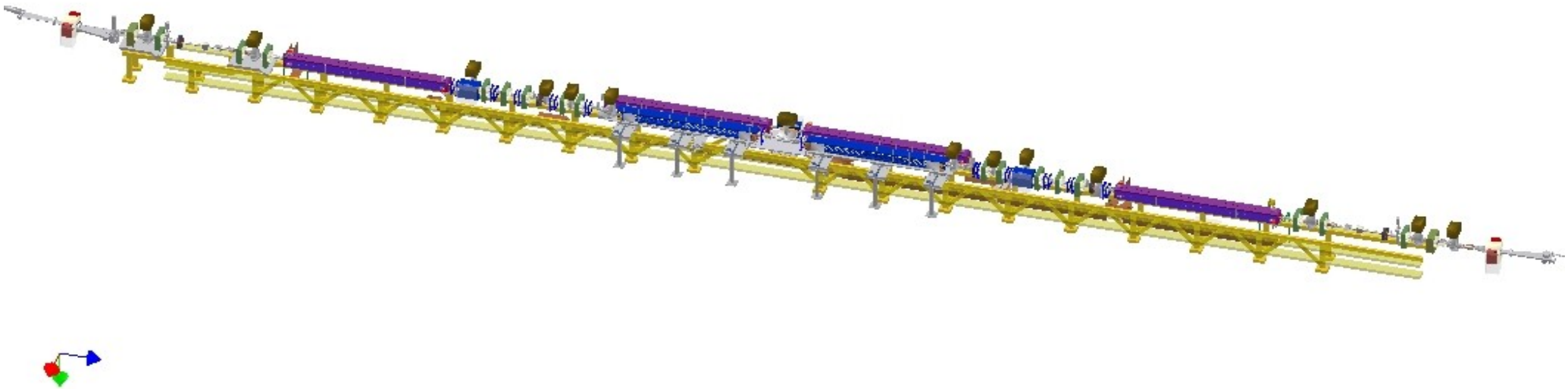
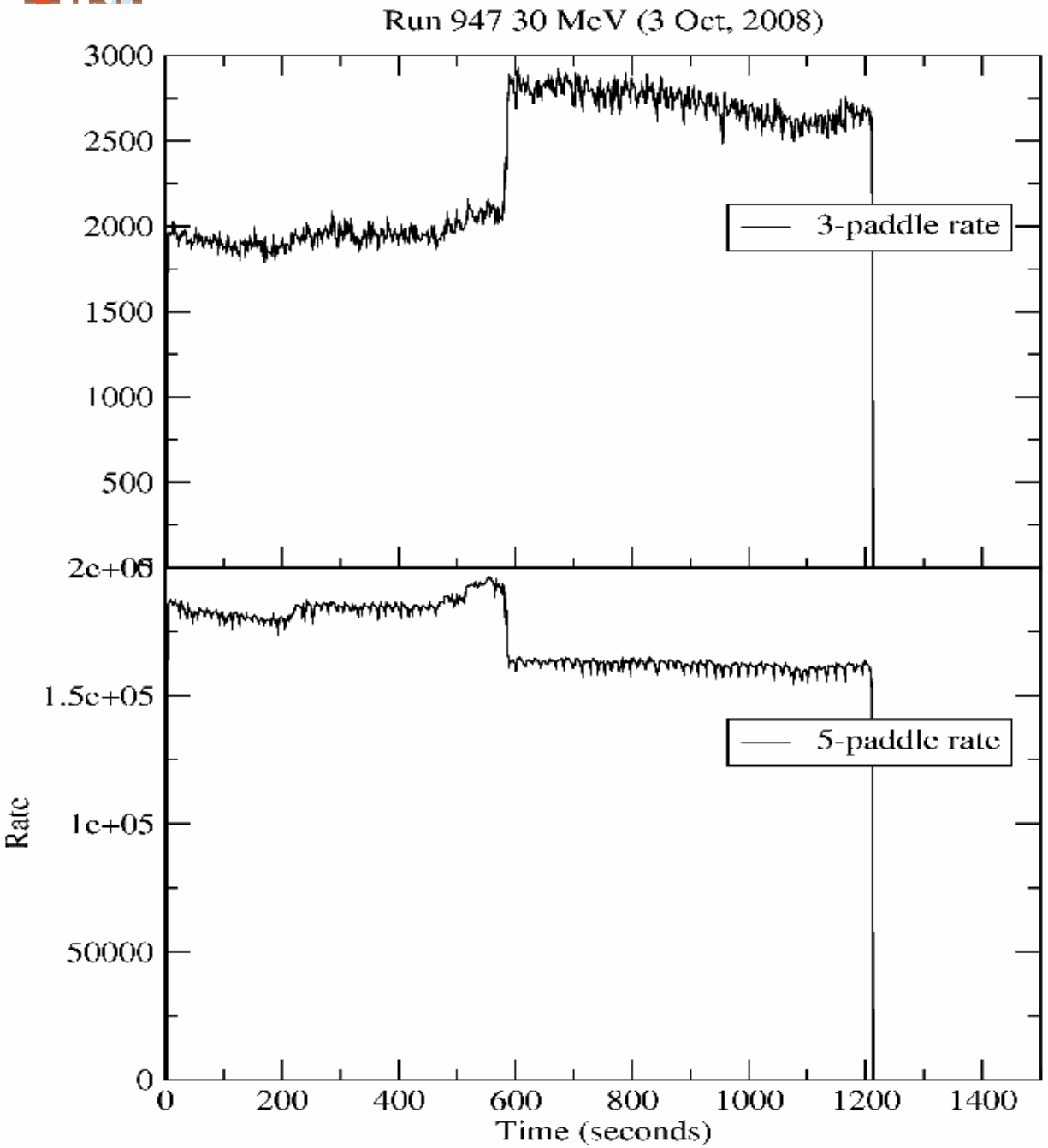


Summary

- **Upgraded High Intensity Gamma-ray Source (HIGS) in 2009**
  - **Capabilities**
    - **Energy Tuning: 1 - 100 MeV**
    - **Maximum Total Flux: ~ 10^{10} γ/s around 5 - 10 MeV**
    - **Maximum Spectrum Flux: : ~ 10^{3} γ/s/eV around 5 - 10 MeV**
    - **High Energy Resolution: 0.8% (< = 5 MeV)**
    - **Polarization: linear, and switchable left- and right-circular**
- **Future Development**
  - **Higher Flux Operation: 10^{11} γ/s total below 20 MeV**
  - **Higher Gamma-beam Energy: 100 - 160 MeV for photon-pion physics research**

First HIGS User Operation in Loss-Mode (20 – 35 MeV)



- Li(g,n), R. Pywell *et al.*
- d(g,n)p, B. Norum *et al.*

On-Target Flux (20 – 35 MeV)
(Collimated by 1" diameter collimator)

$6 \times 10^6 - 1.3 \times 10^7$ g/s

Courtesy of Rob Pywell, U. of Saskatchewan

In-Cavity, Water-cooled Apertures

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

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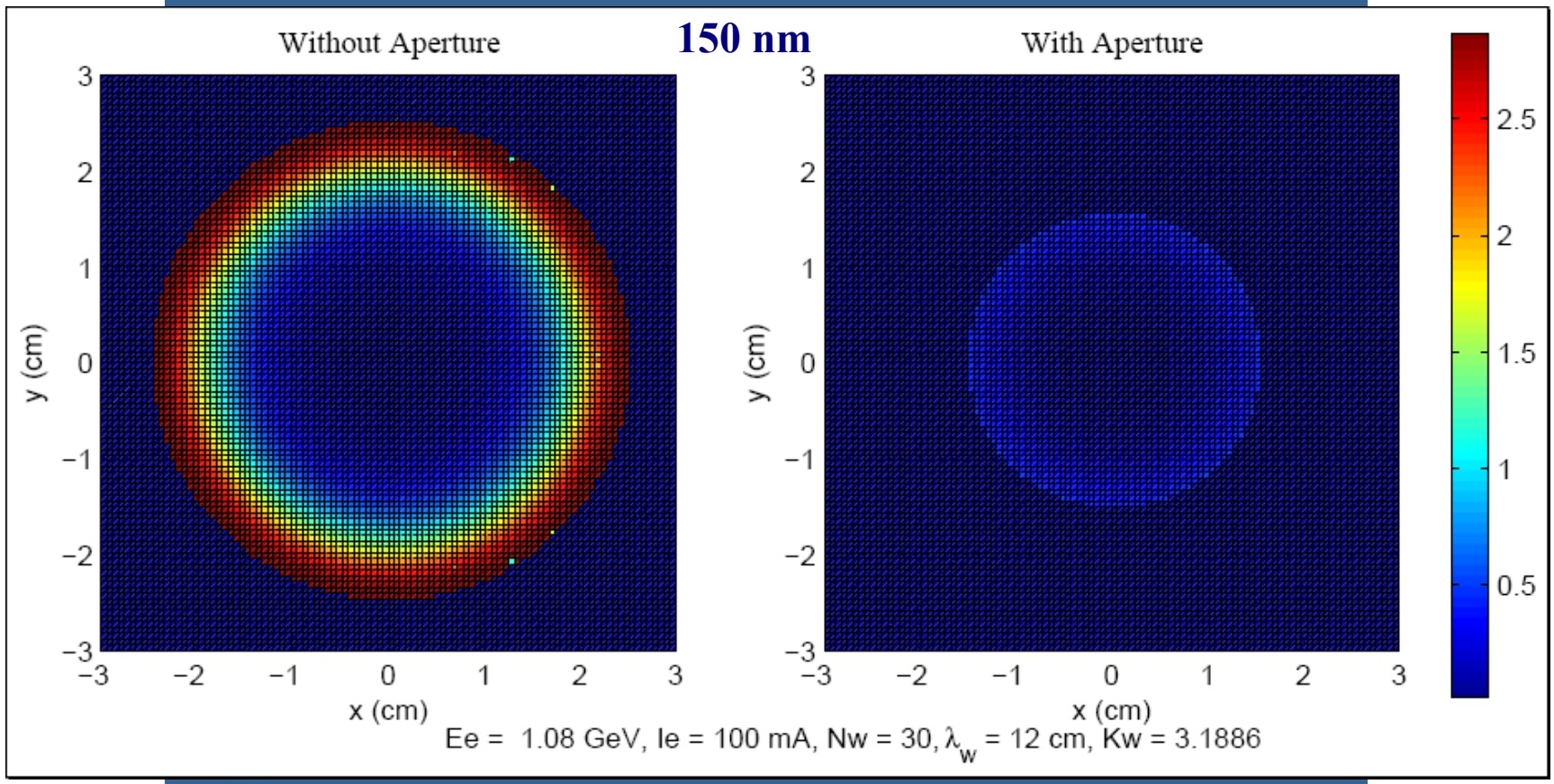

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