First Demonstration of High Gain Lasing and Polarization Switch with a Distributed Optical Klystron FEL at Duke University

Y. K. Wu[*], N. A. Vinokurov[#]

S. Mikhailov[*], J. Li[*], V. Popov[*]

[*]FEL Lab, Department of Physics, Duke University

[#]Budker Institute of Nuclear Physics (BINP, Russia)

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Acknowledgments

Members of Duke FEL Lab (DFELL) Team (former and present)

DFELL Scientists:

J. Li, S. Mikhailov, V. Popov, Y. K. Wu

DFELL Engineering and Technical Staff:

M. Busch, M. Emamian, J. Faircloth, S. Hartman, J. Marty, O. Oakley, J. Patterson, M. Pentico, V. Rathbone, G. Swift, P. Wallace, P. Wang

Former DFELL Scientists:

V. N. Litvinenko (BNL since 2003)

I. V. Pinayev (BNL since 2004)

Members of Budker Institute of Nuclear Physics (BINP, Russia) Team

N. A. Vinokurov, N. G. Gavrilov,

O. A. Shevchenko, P. D. Vobly, G. N. Kulipanov

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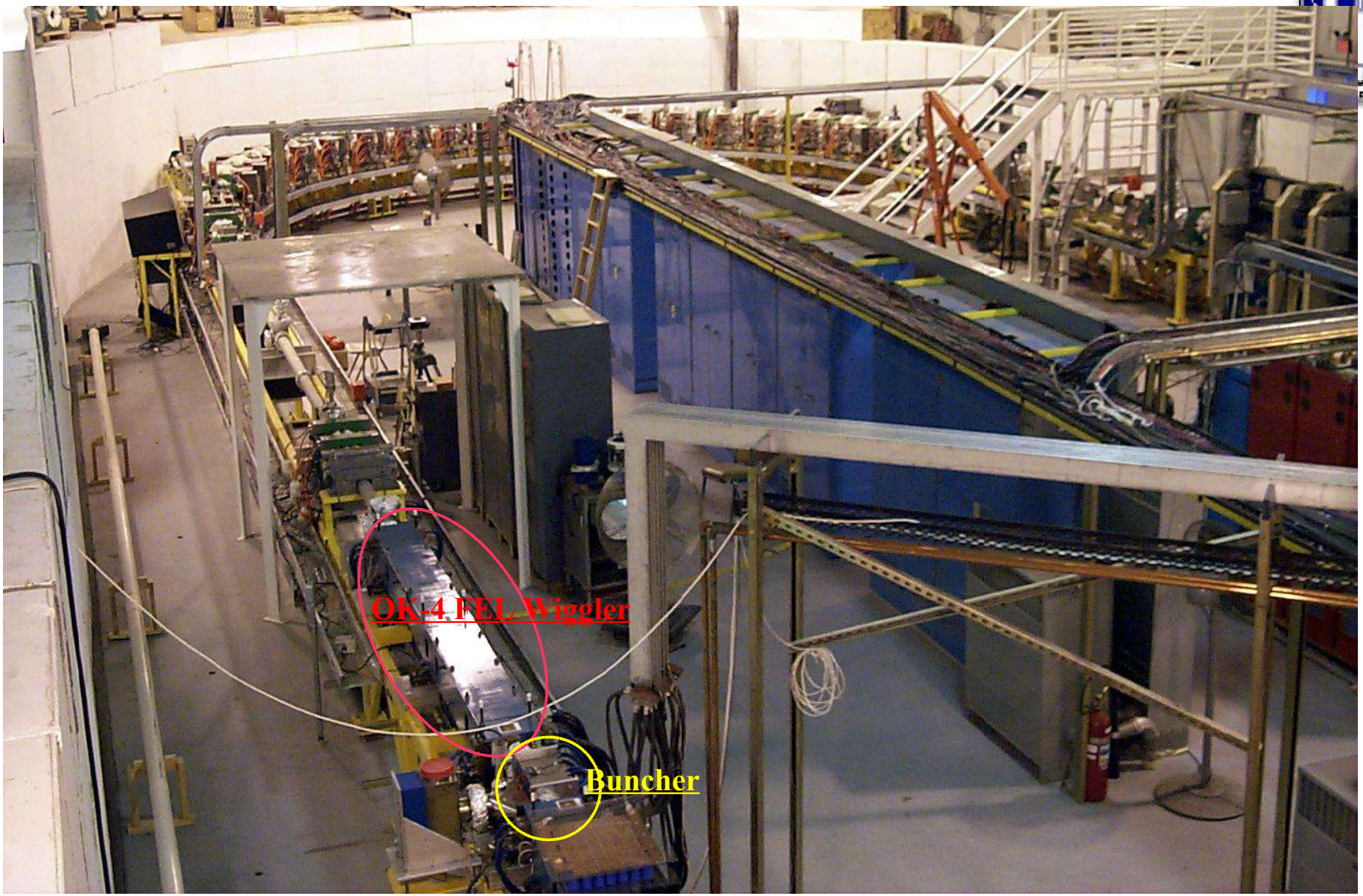
Outline

- **FEL Upgrade Project at Duke University: 2003 – 2005**
  - **Two New FELs: OK-5 FEL and DOK-1 FEL**
- **High Gain Operation and Polarization Switch with DOK-1 FEL**
- **Near-Term Light Source Development**

2003 – 2006 FEL Upgrade at Duke

New South Straight Lattice for FELs
HOM-damped RF System
New FELs with two OK-5 wigglers

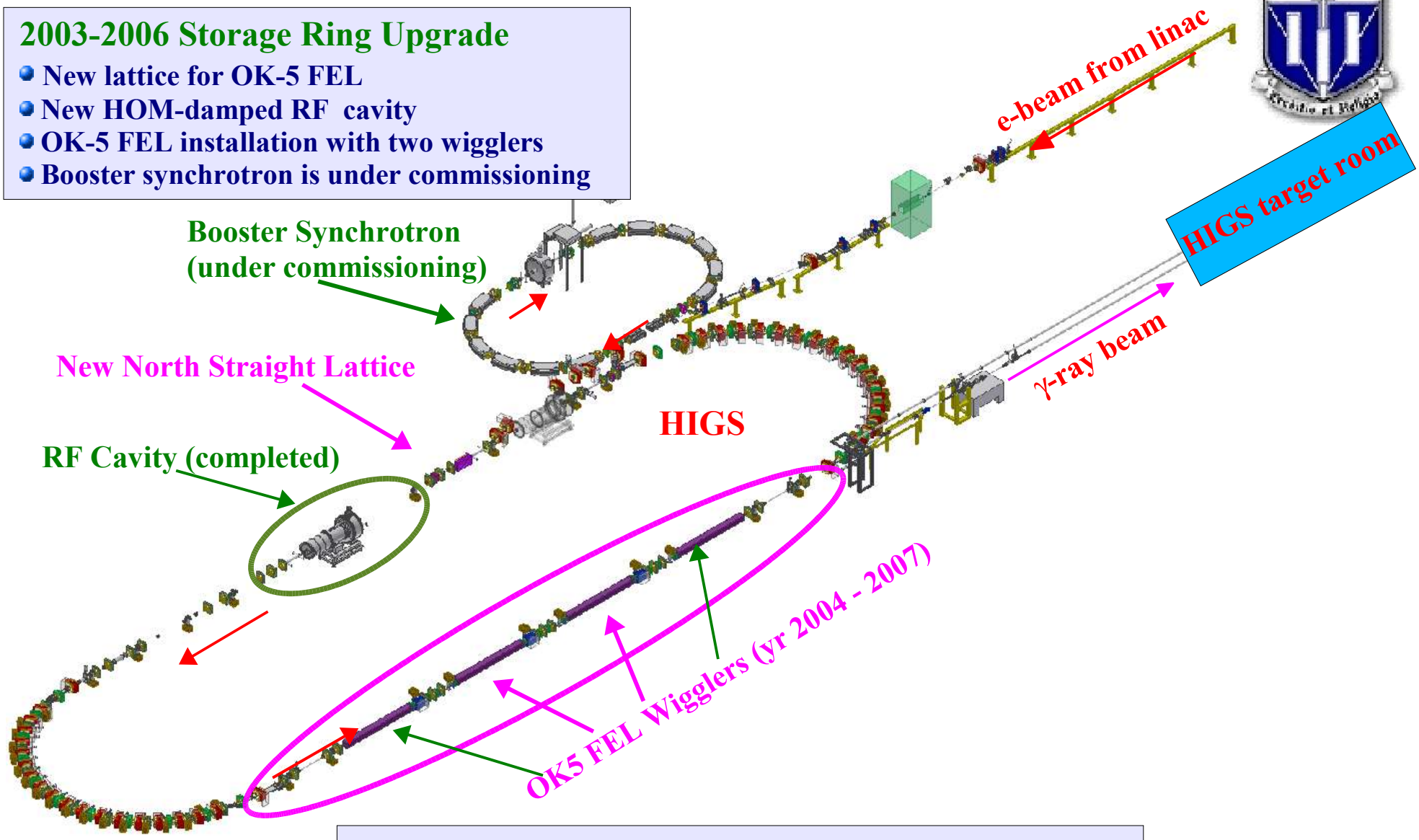
Duke FEL Storage Ring (0.25-1.2 GeV, 108 m, 1996-2004)



DFELL Facility after Full Upgrades in 2007

2003-2006 Storage Ring Upgrade

- New lattice for OK-5 FEL
- New HOM-damped RF cavity
- OK-5 FEL installation with two wigglers
- Booster synchrotron is under commissioning

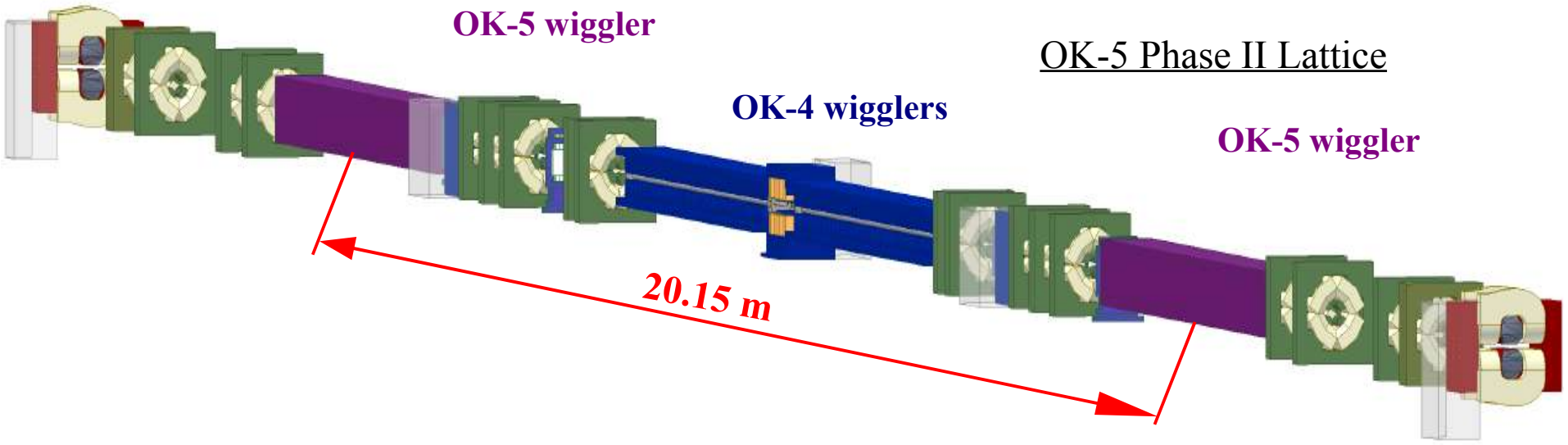


Fully Upgraded Facility (2006)

- Top-off injection, continuous gamma-ray operation
- Typical mode: 8-bunch, 20 mA/bunch

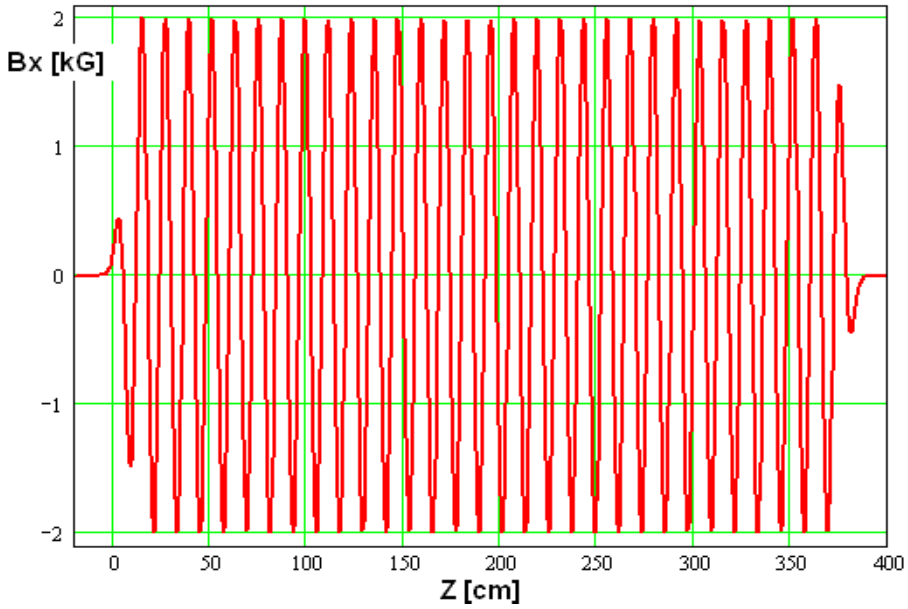
OK-5 Phase II Lattice Upgrade (2004-2005)

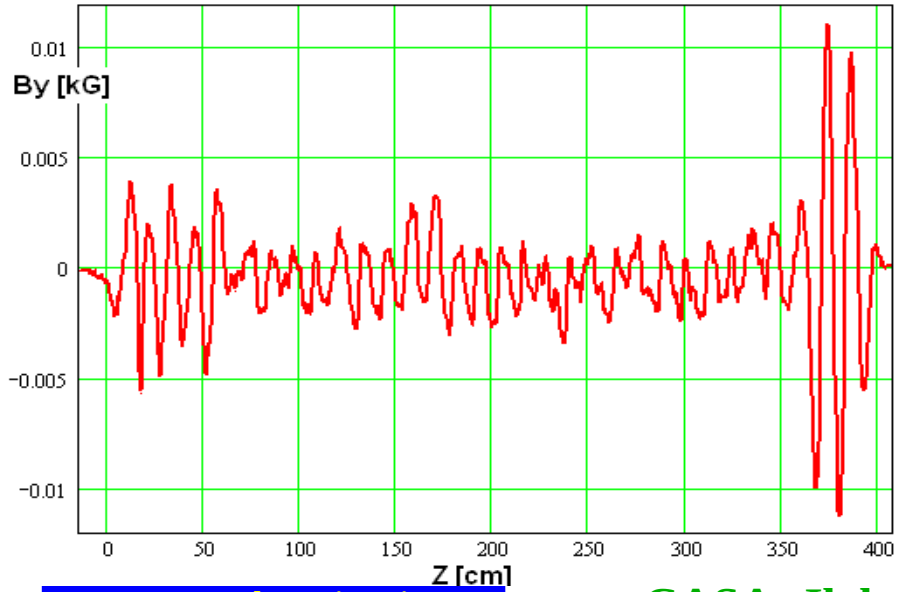
- Study dynamics impacts of OK-5 wigglers
- Retain OK-4 FEL as the user light source
- Commission main part of OK-5 magnetic optics
- Commission the OK-5 FEL with two wigglers
- Study operation of OK-4 and OK-5 together



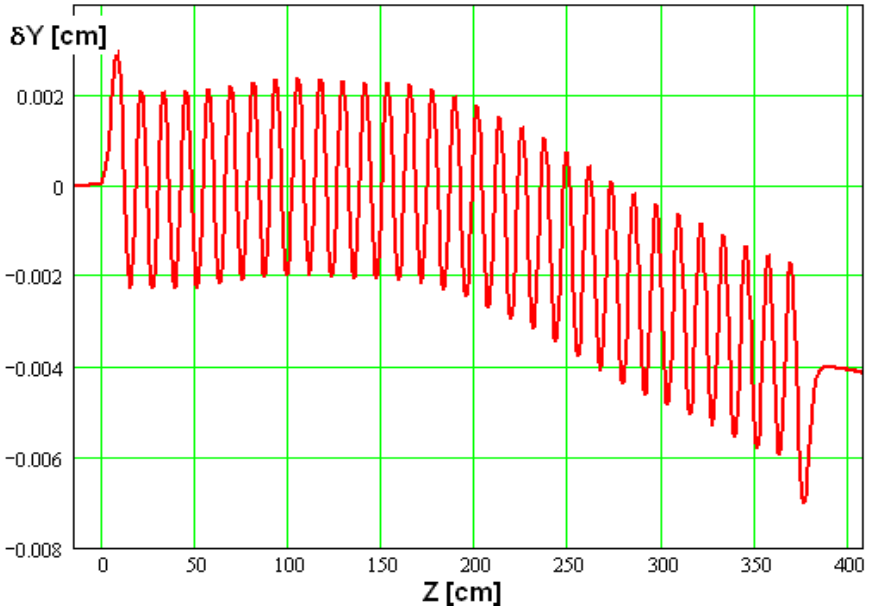
OK-5 Wiggler Field Measurements Ix = 0 A, Iy = 2.0 kA

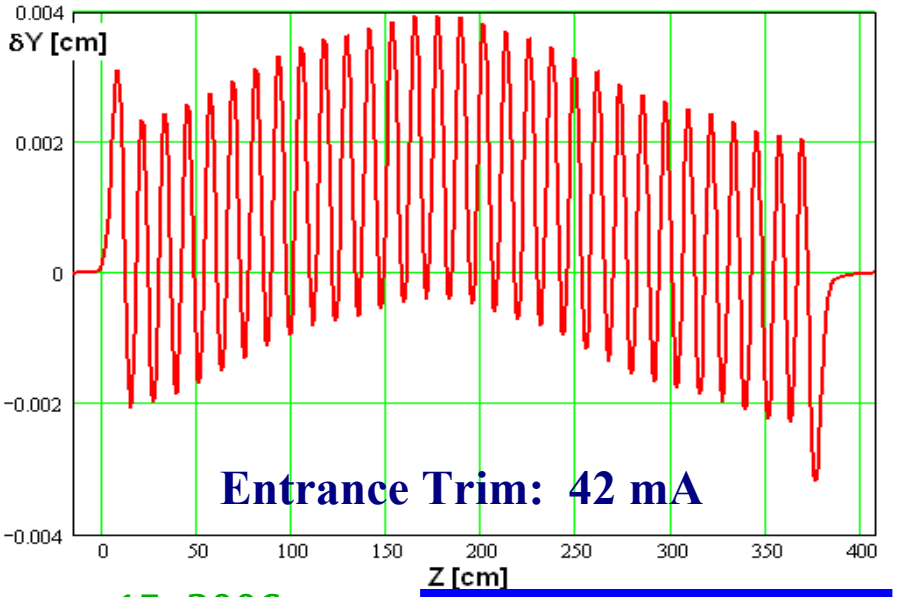
Measured Magnetic Fields





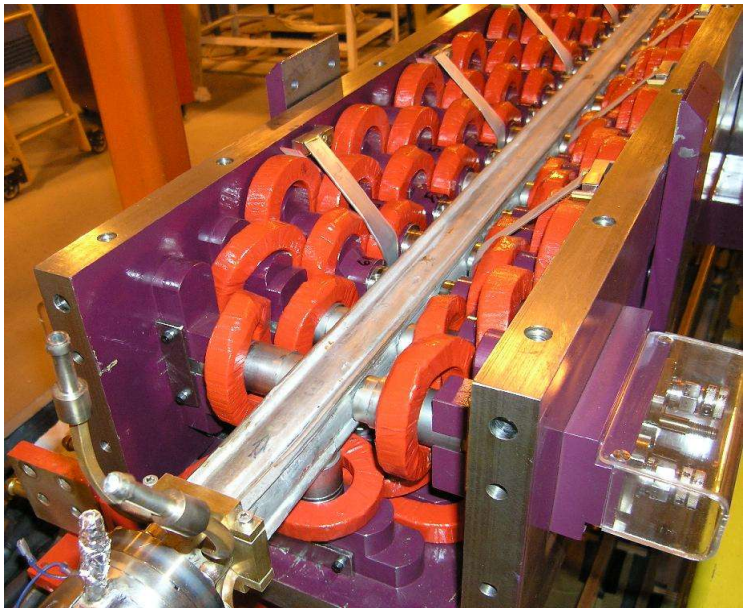
Vertical Orbit at 1 GeV





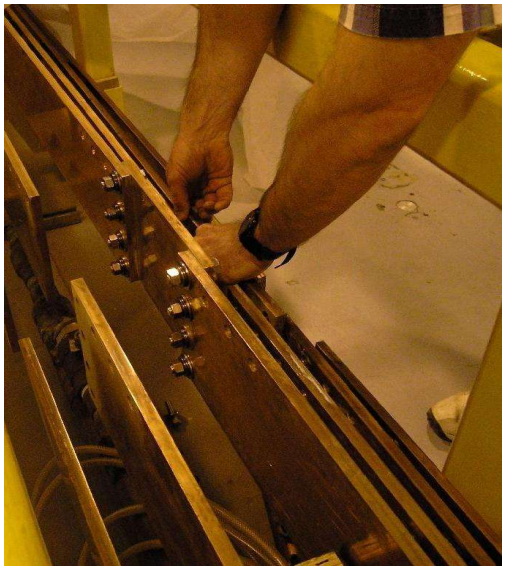
Entrance Trim: 42 mA

OK-5 Wiggler Installation

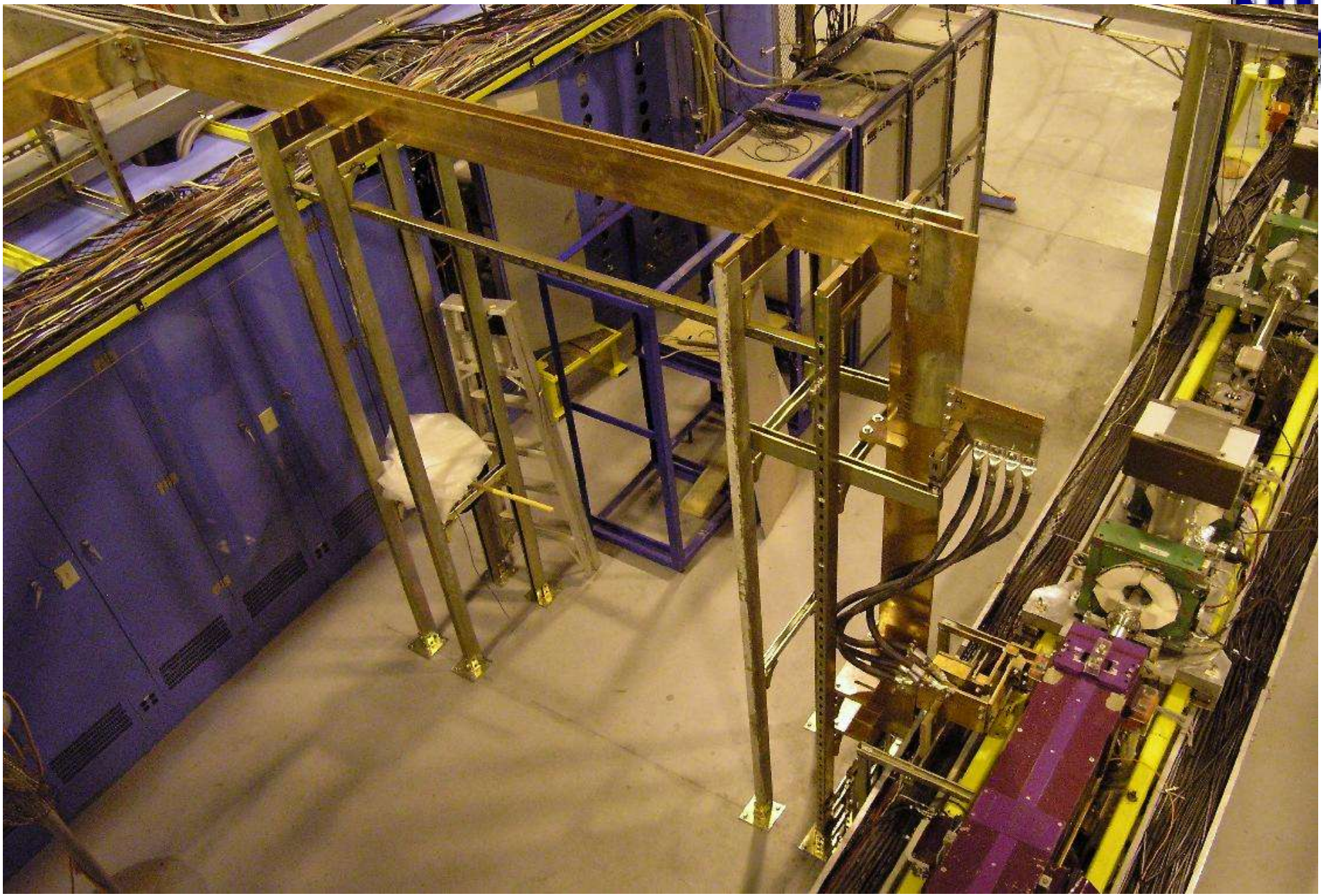


T-Rex Power Supplies for Wigglers (0-3000 A)

Wiggler Bussbars



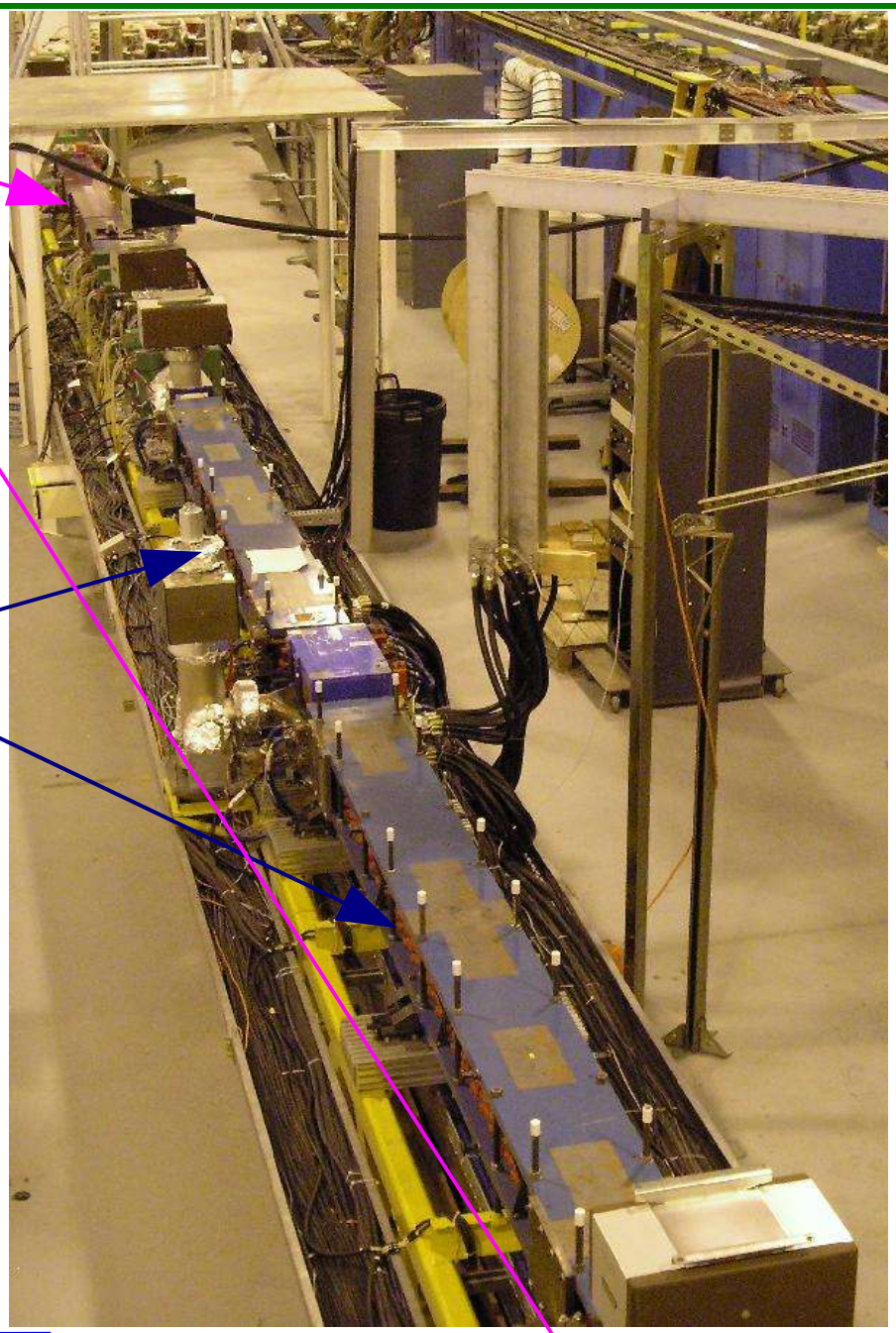
Bussbar System



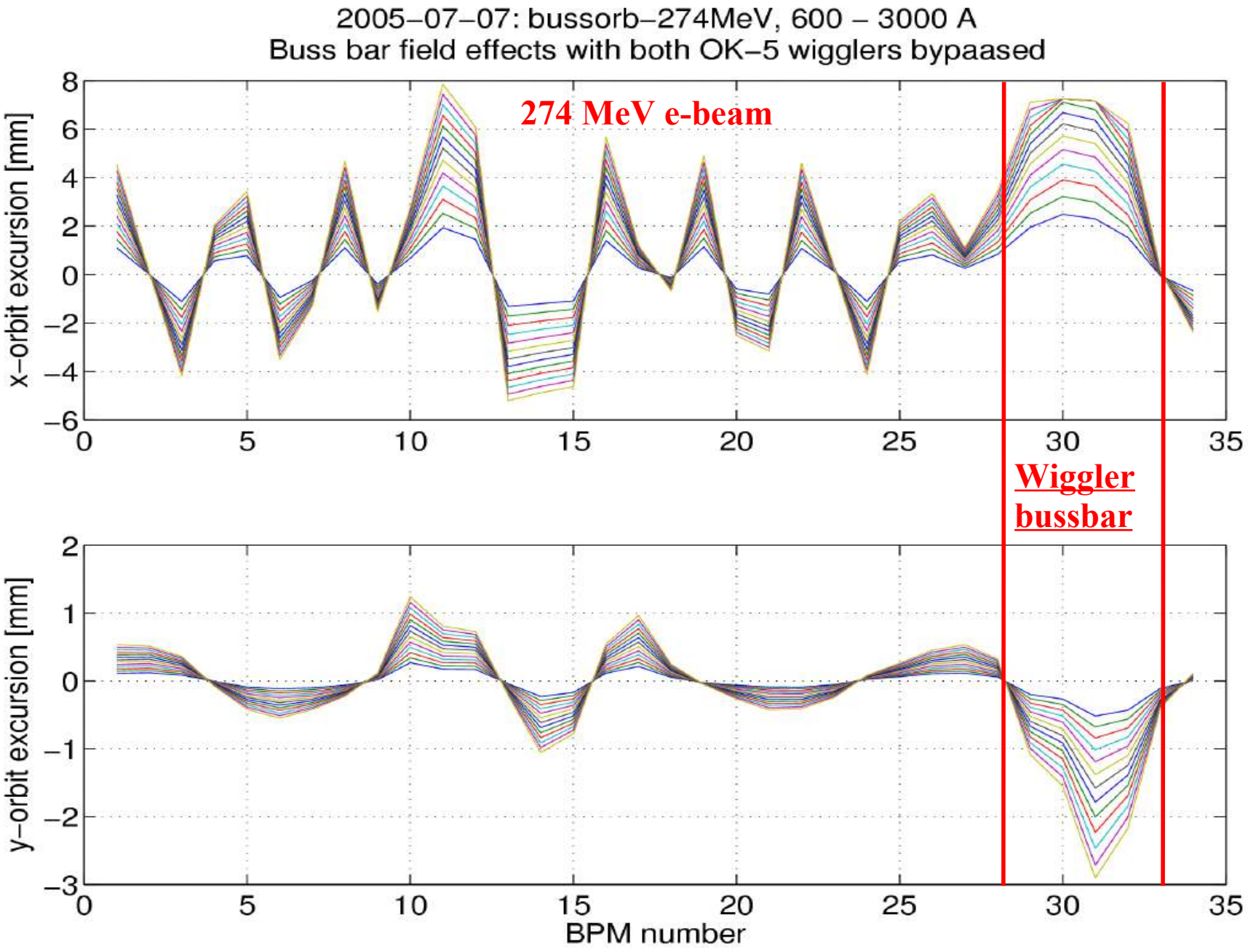
OK-5 and OK-4 FELs (Aug. 2005)

OK-5 wigglers

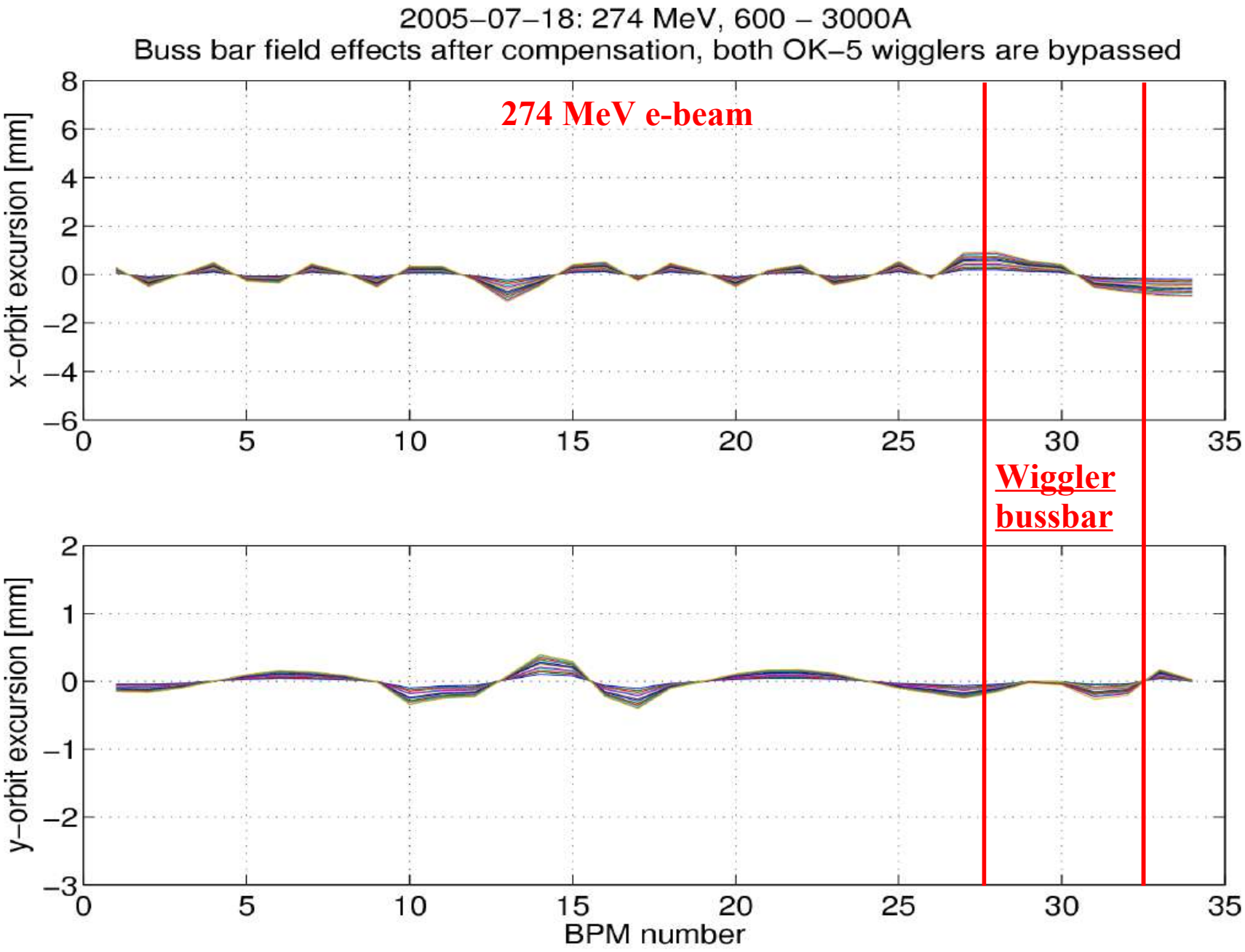
OK-4 wigglers



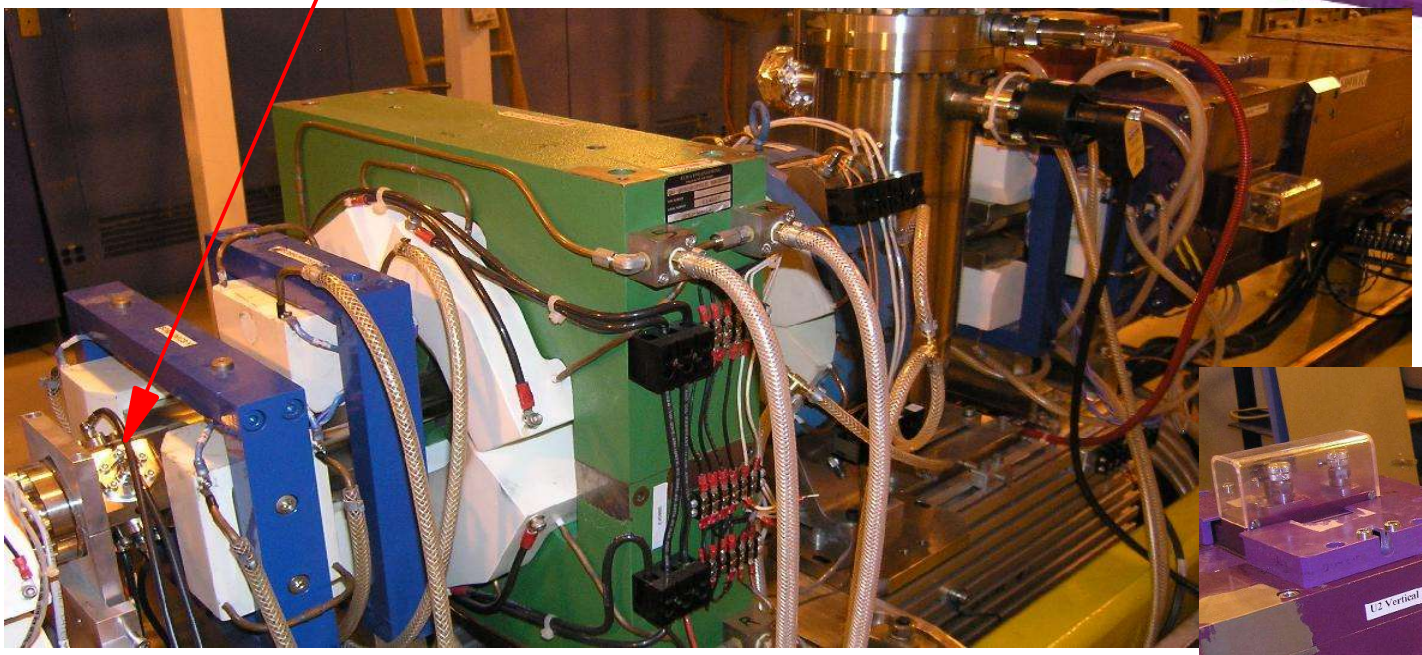
Bassbar Impact on Beam Orbit

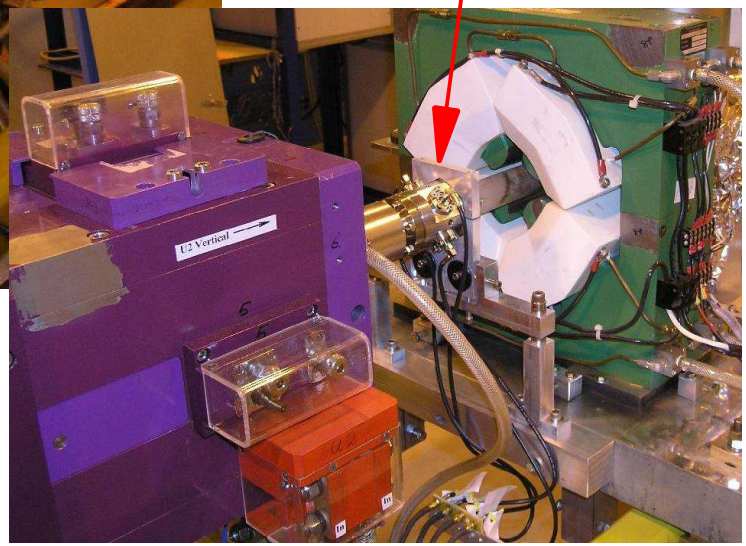


Bassbar Impact on Beam Orbit

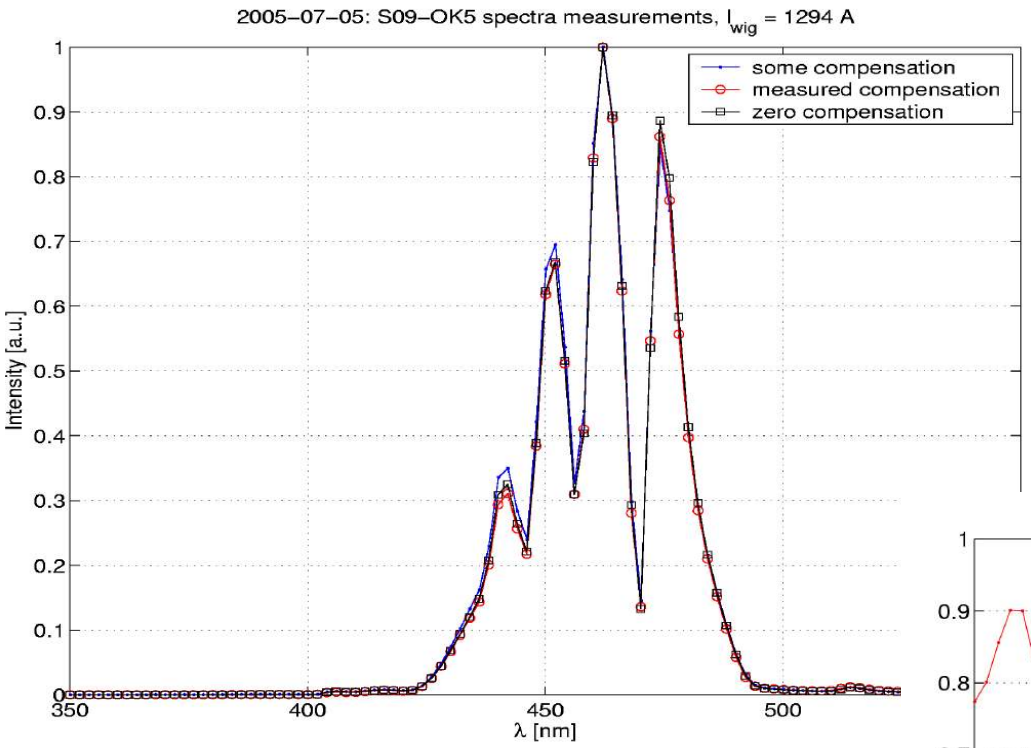


Limited Beam Diagnostics Capabilities



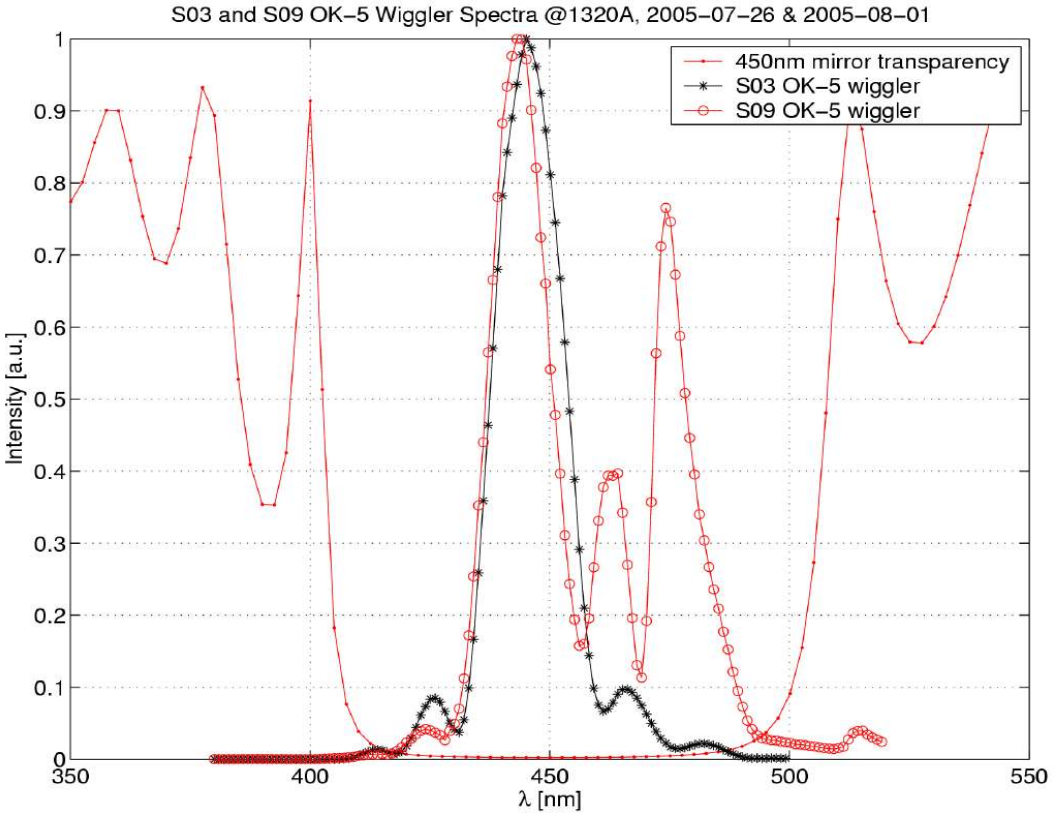


Spectra Improvement for OK-5 Wigglers (Horizontal Polarization)

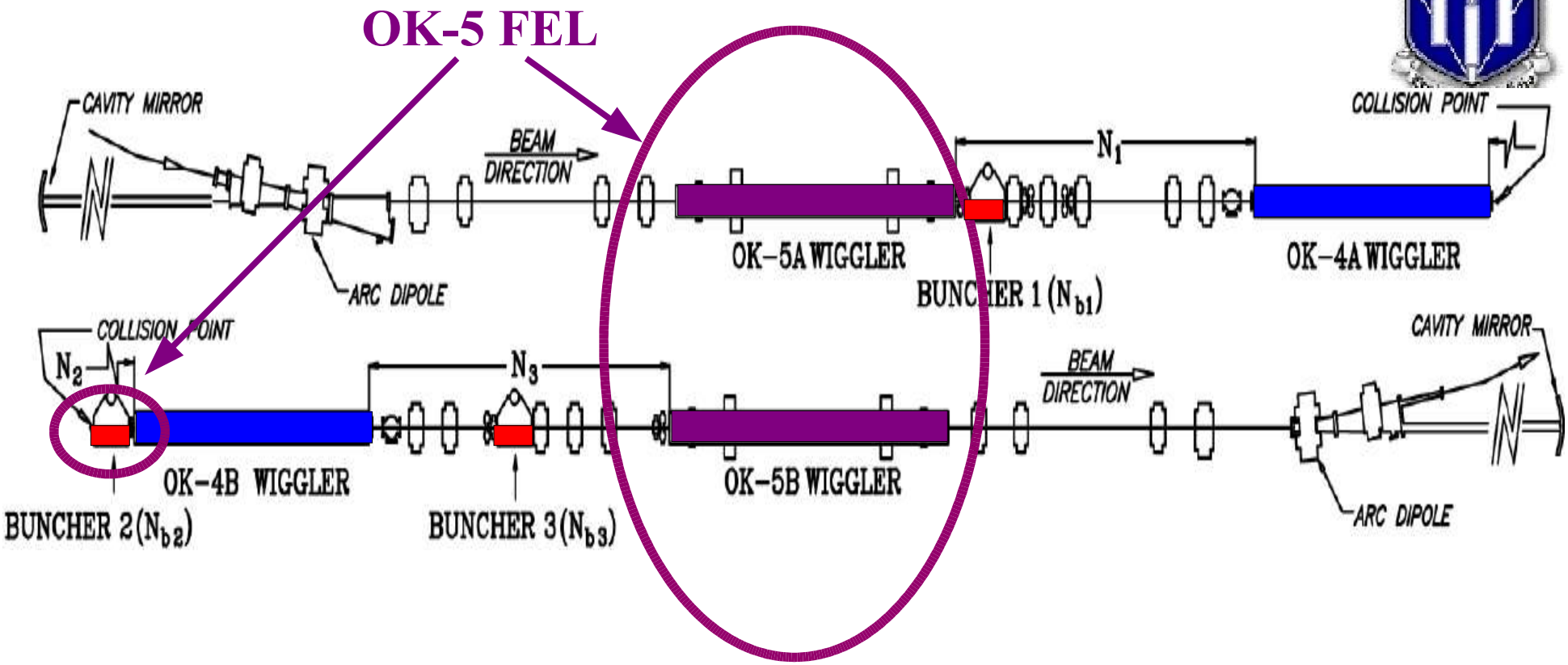


Before orbit correction:
Two wigglers together

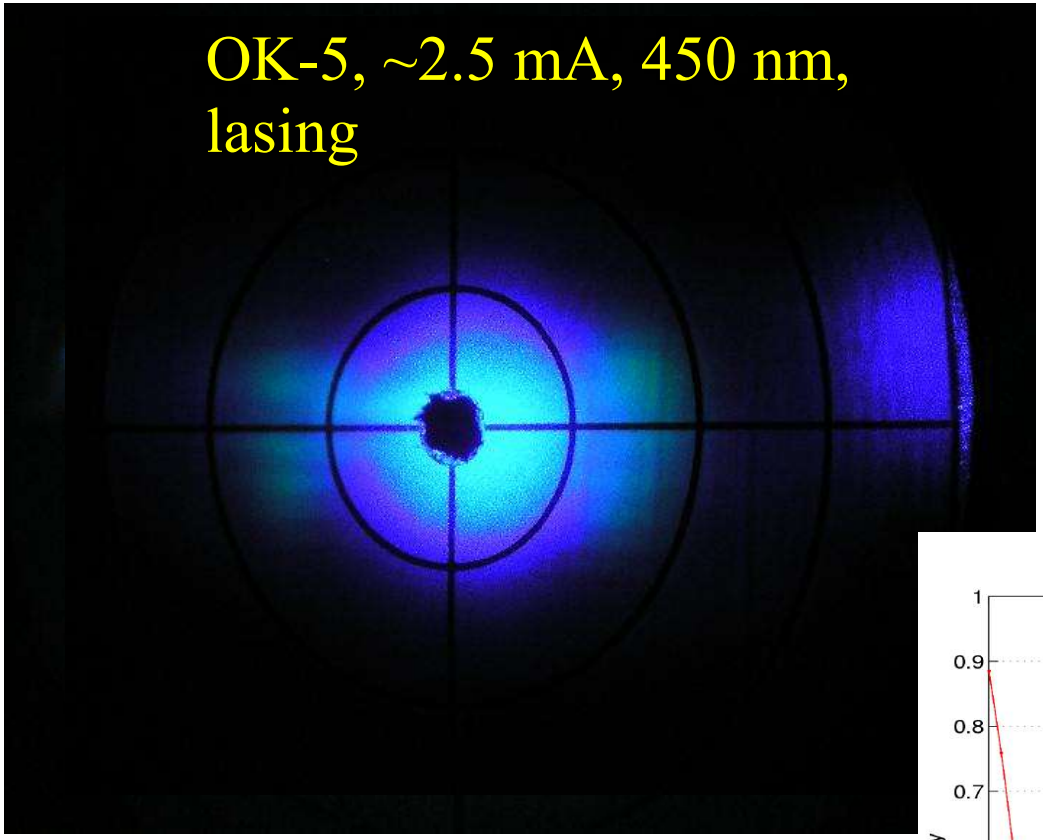
After orbit correction:
individual wigglers

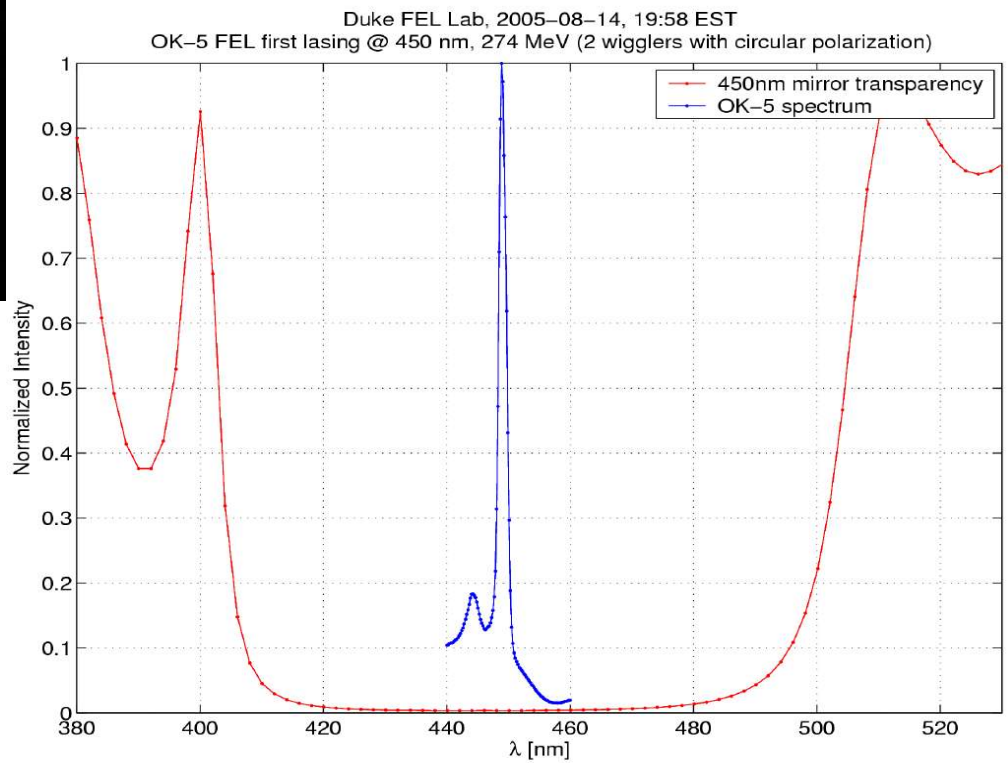


OK-5 FEL and DOK-1 FEL Layout



OK-5 FEL: No Lasing vs Lasing (450 MeV)

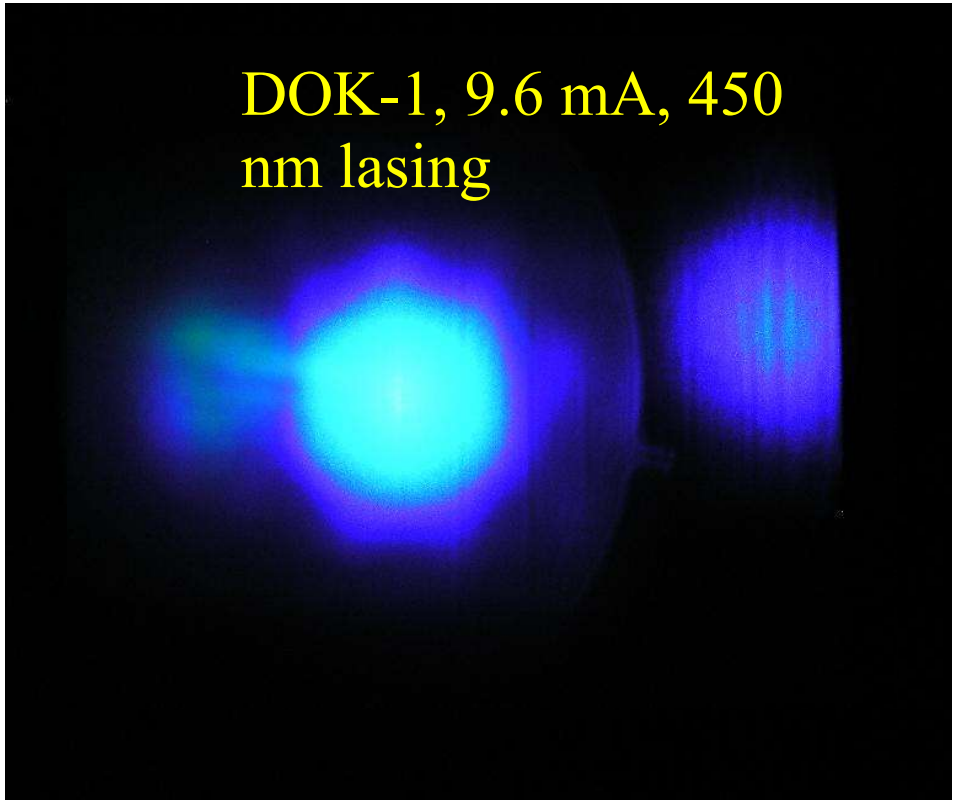


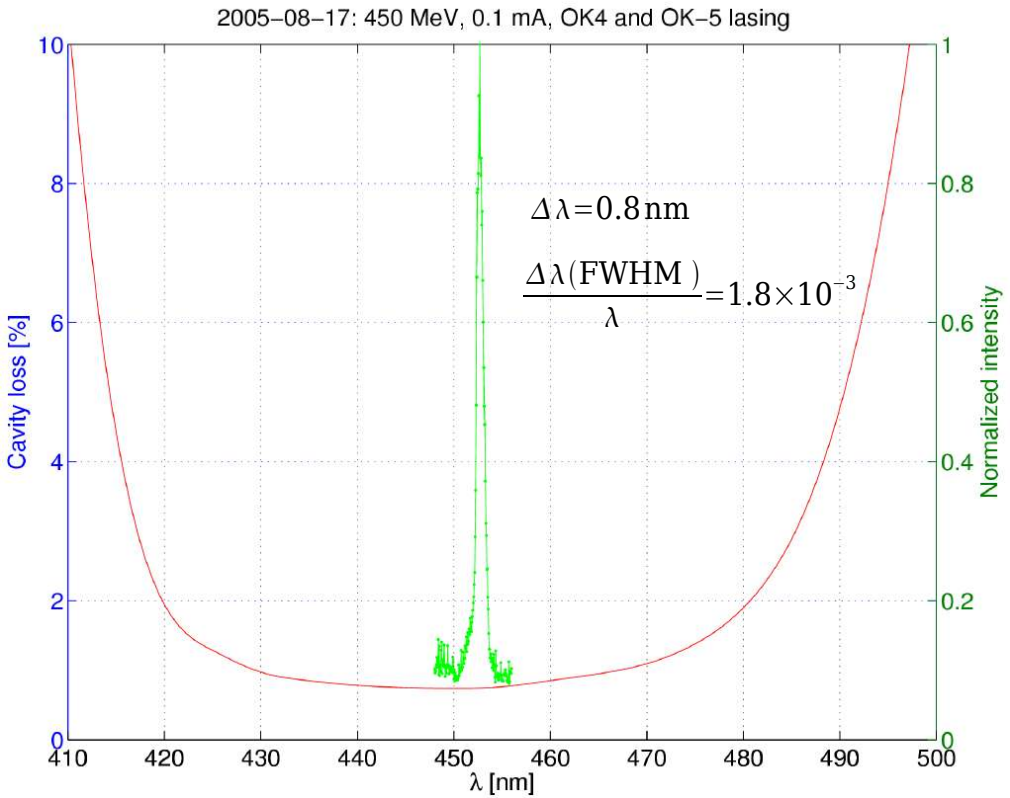


OK-5 FEL (Circular):

two helical wigglers, 20 m apart

DOK-1: No Lasing vs Lasing (450 MeV)





DOK-1 FEL (Mixed Polarization):

two circular (OK-5) wigglers

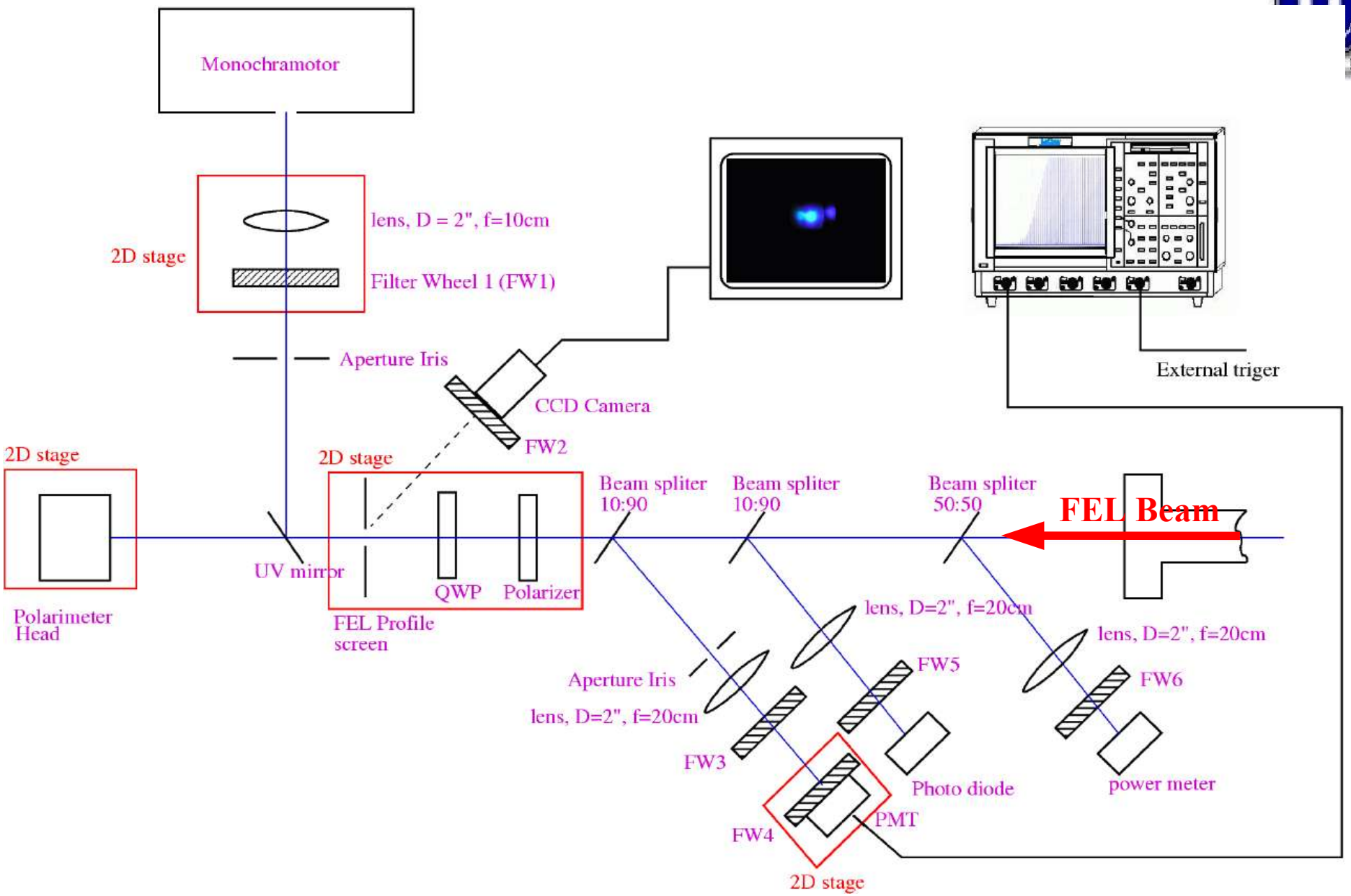
+

two horizontal (OK-4) wigglers

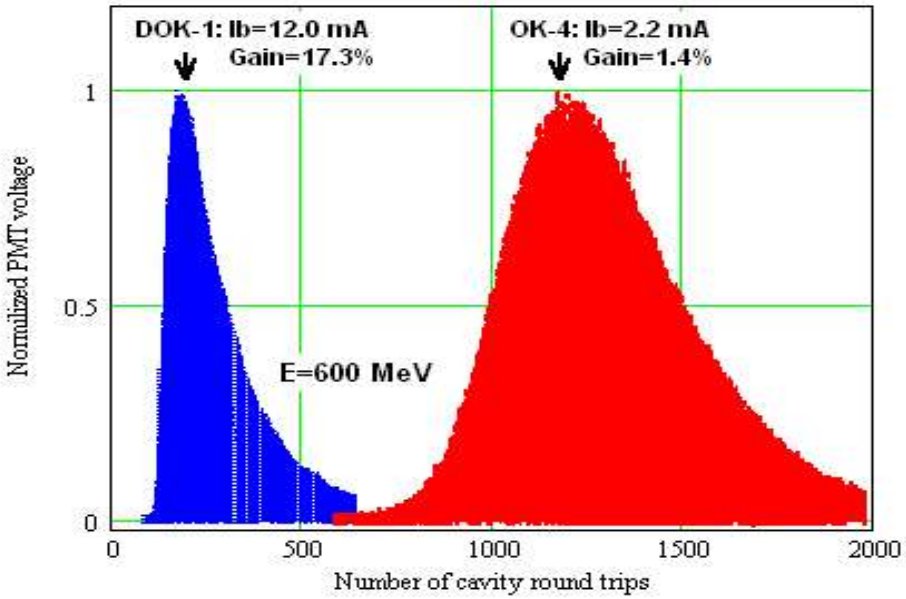
Recent DOK-1 FEL Measurements

High Gain Operation and Polarization Switch

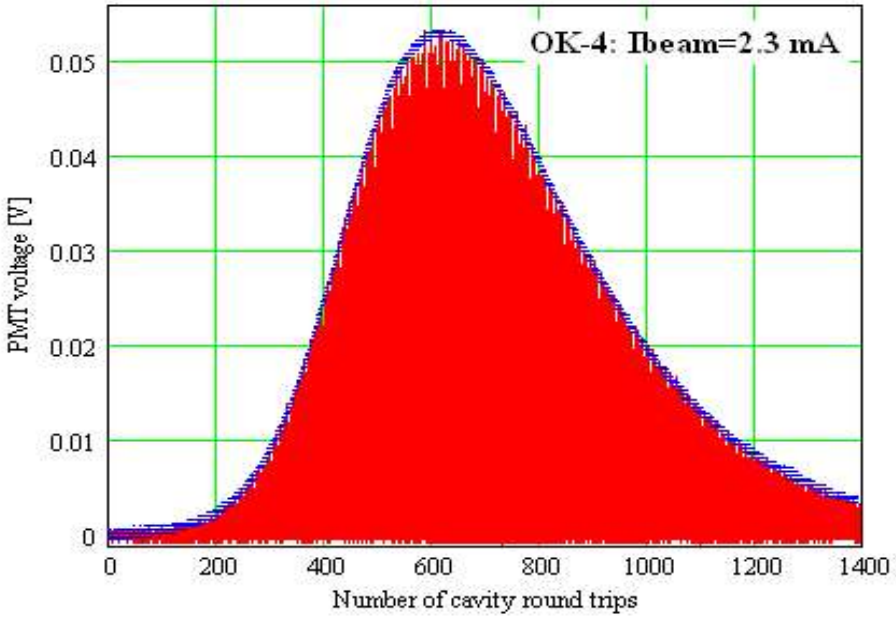
FEL Measurement Setup

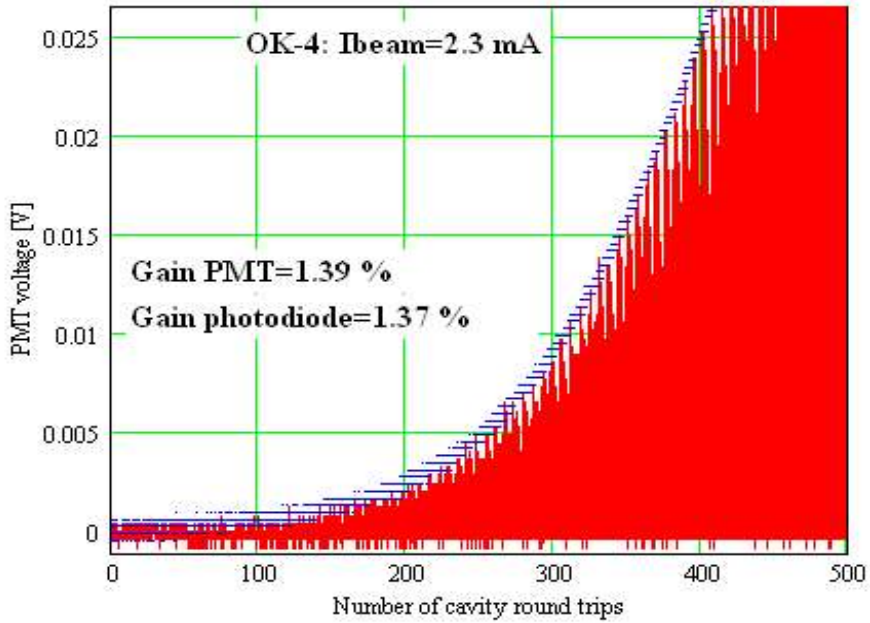


Giant Pulse Operation (G-Switch Operation)

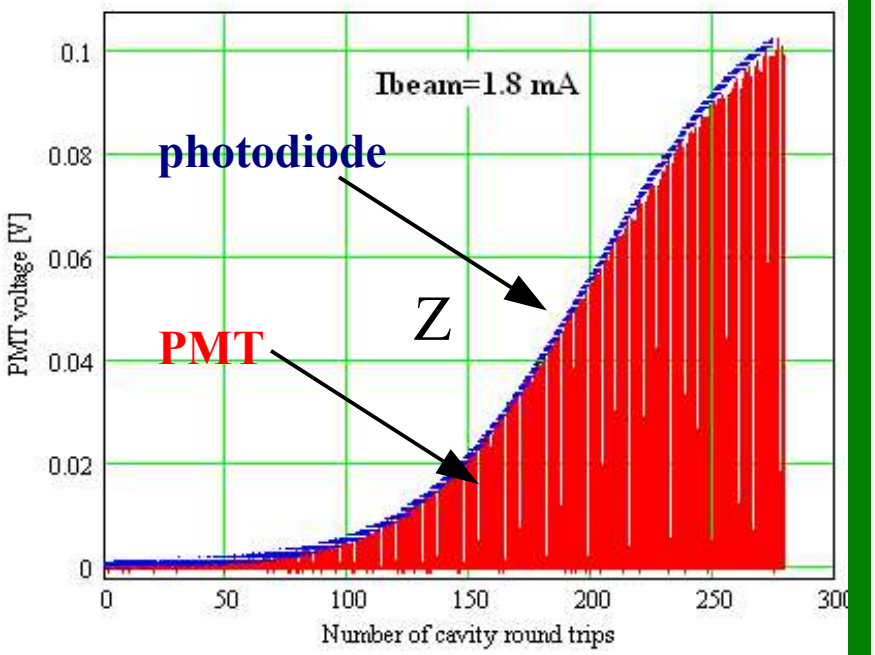


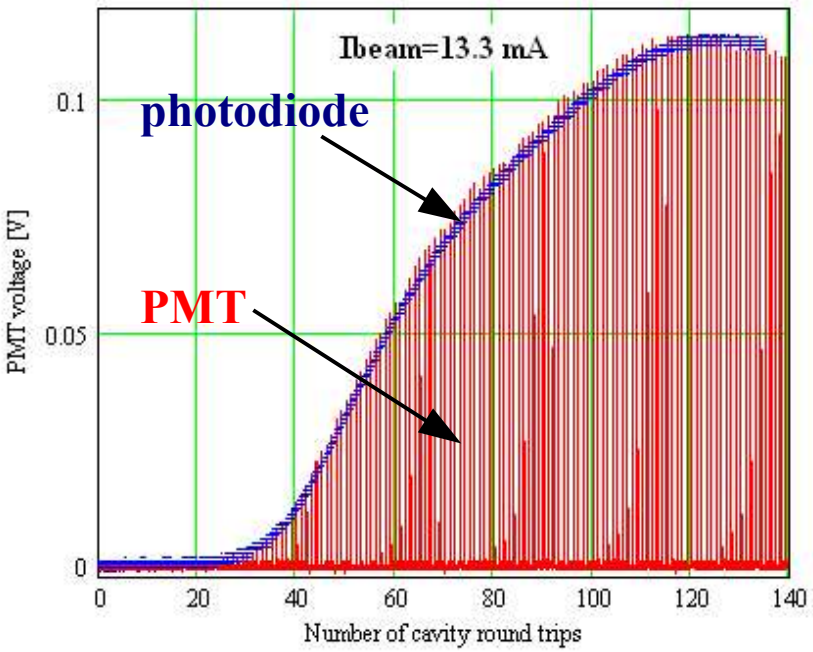
T= 0.36 μs

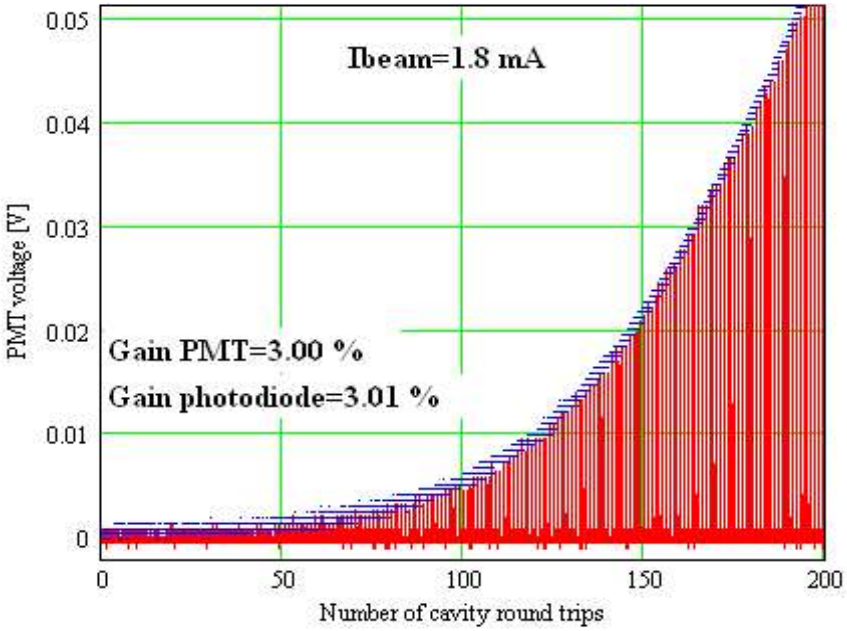


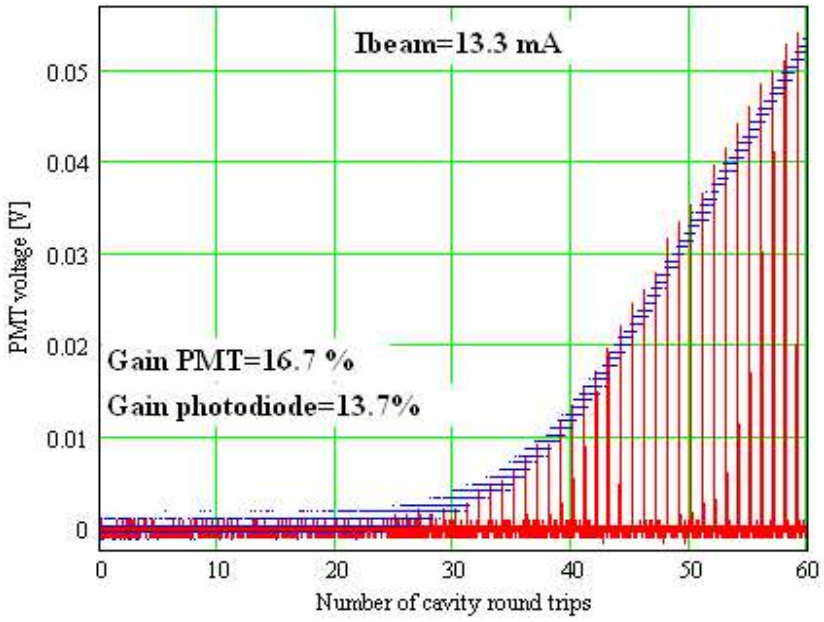


PMT vs Photo-diode

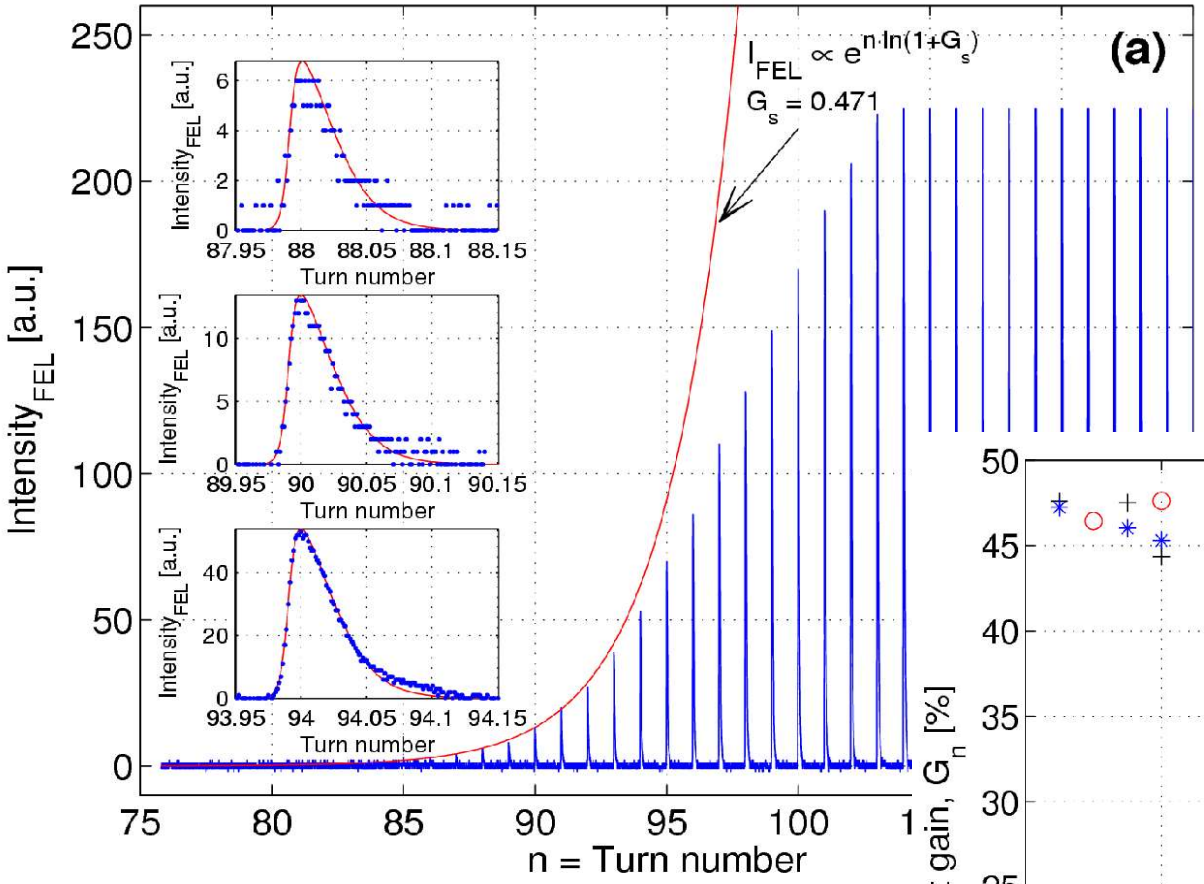




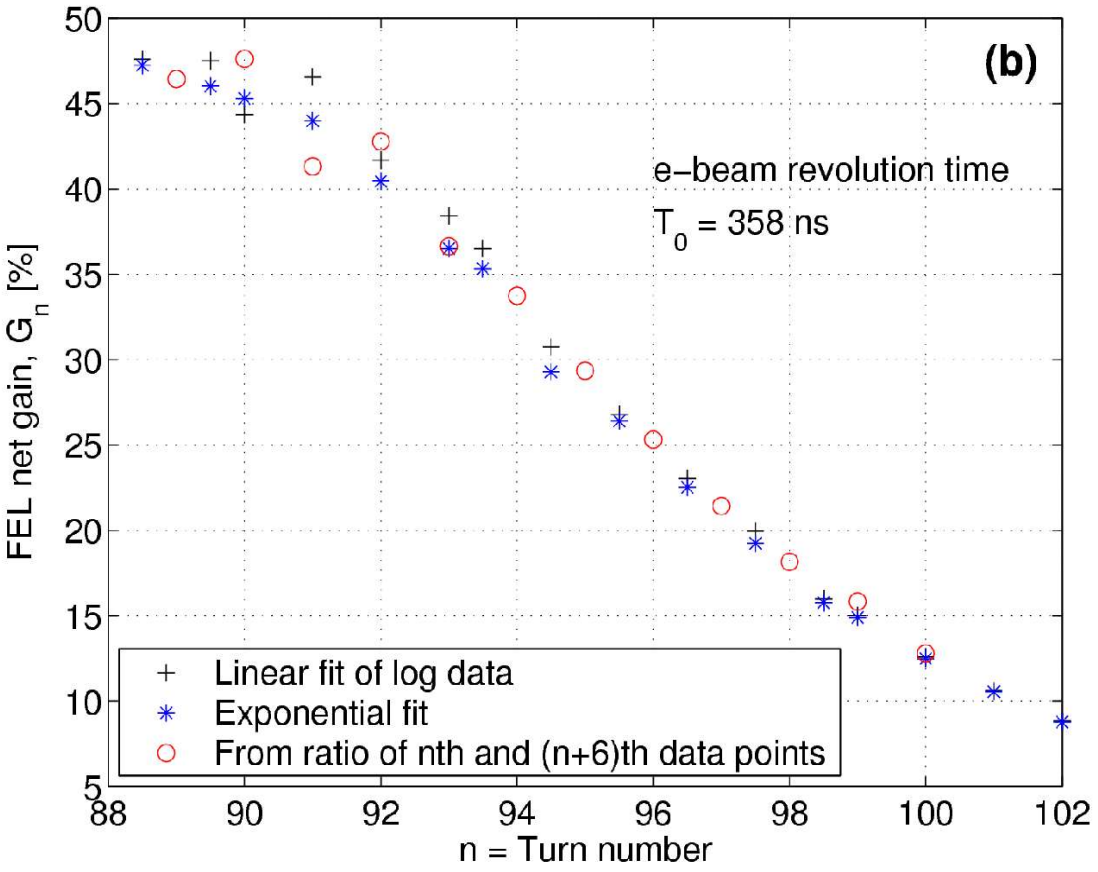




DOK-1 FEL Gain Measurement



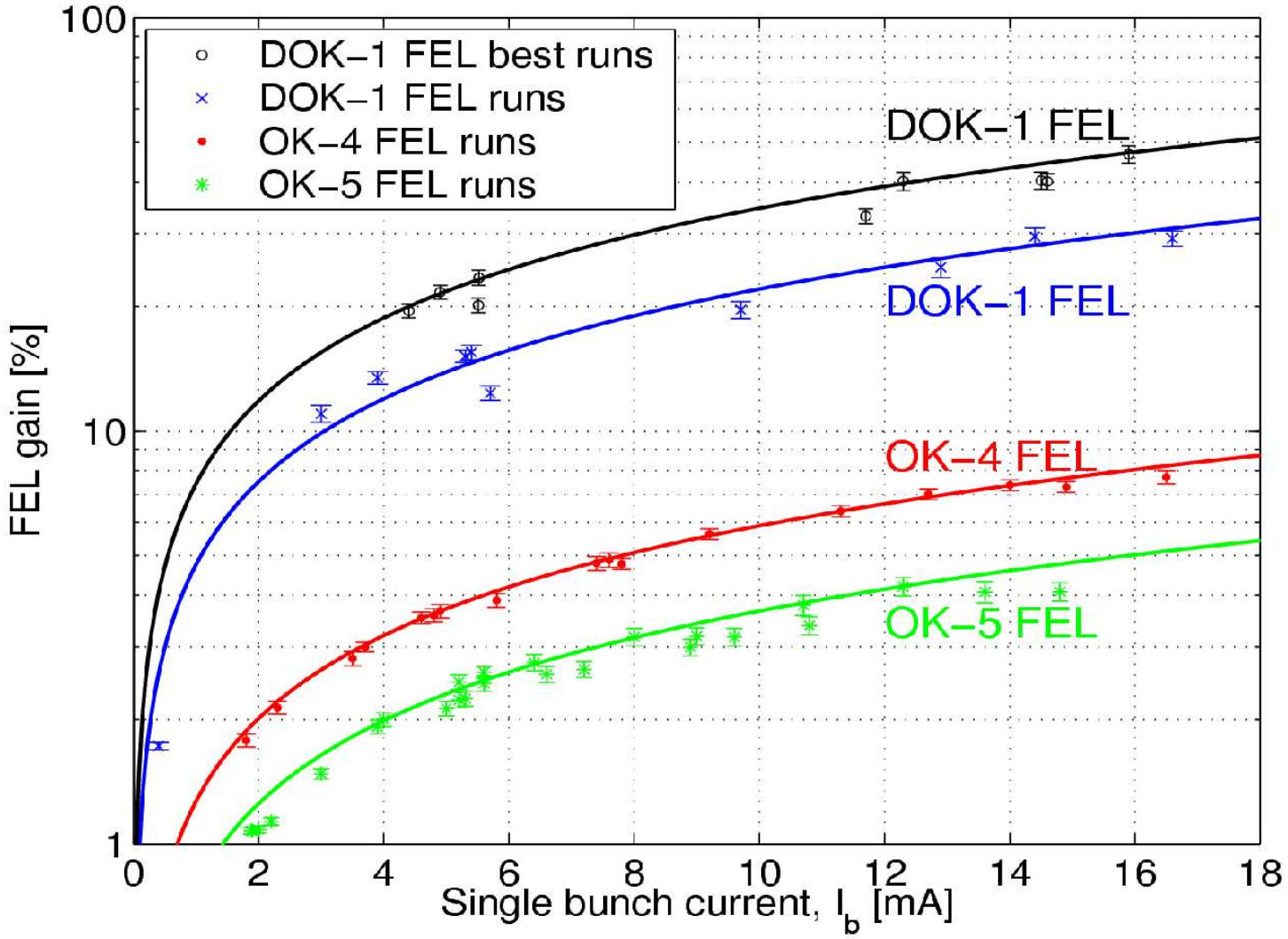
V. N. Litvinenko, *High gain distributed optical klystron*, NIMA 304, 1991



Max Gain: 47.8% (+/-2.7%)
with 16 mA of bunch current

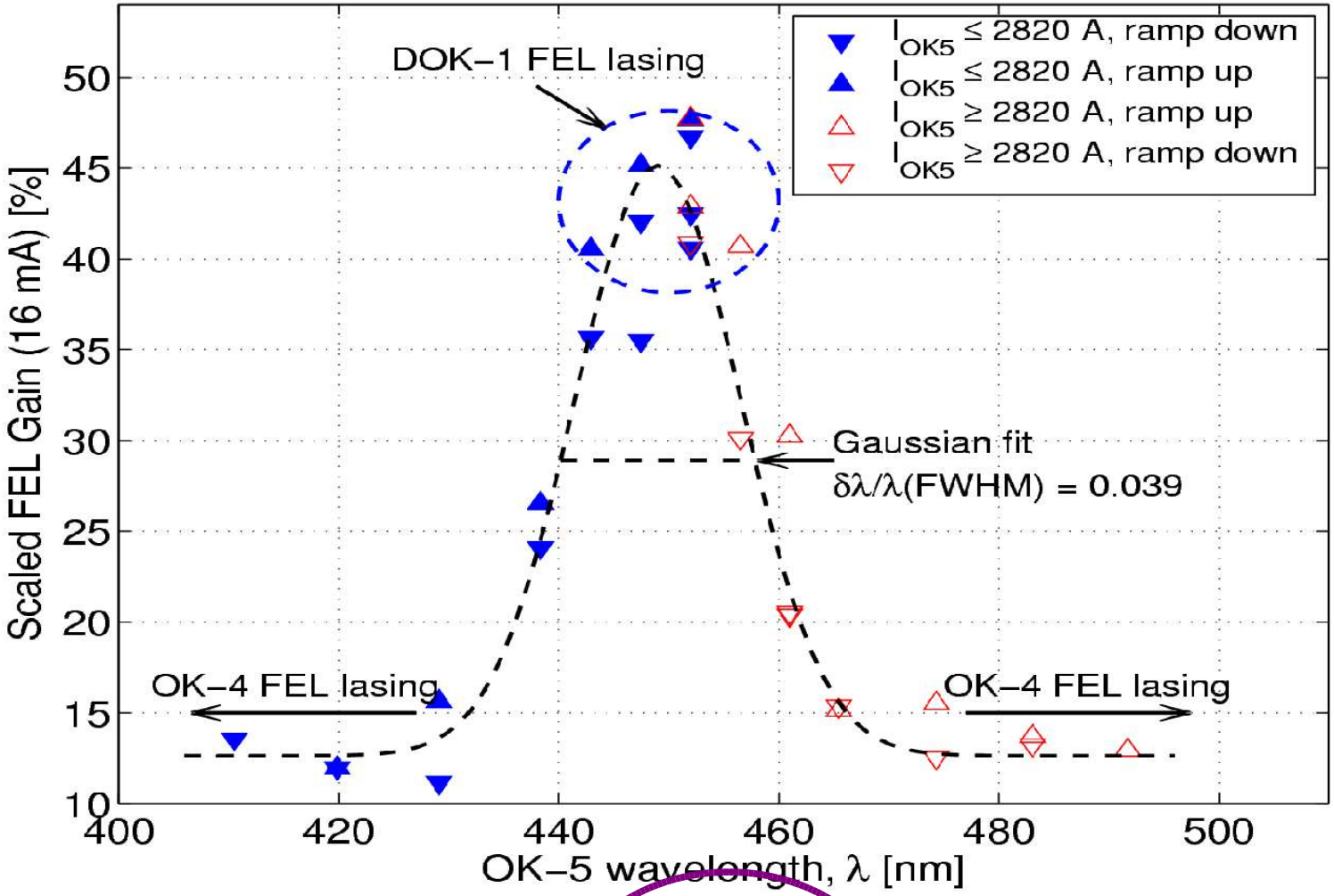
Peak current: ~29 A
Energy spread (σ_E/E): ~1.4e-3

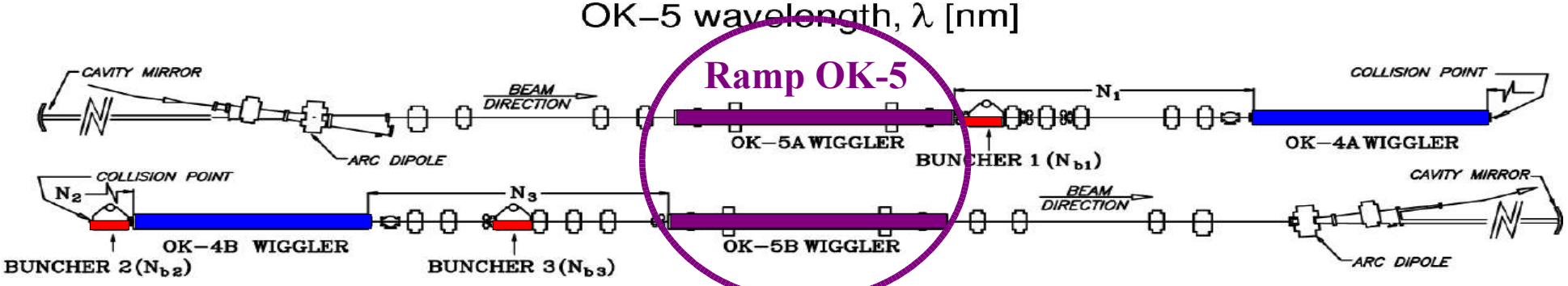
OK-4, OK-5, DOK-1 FEL Gain vs Current



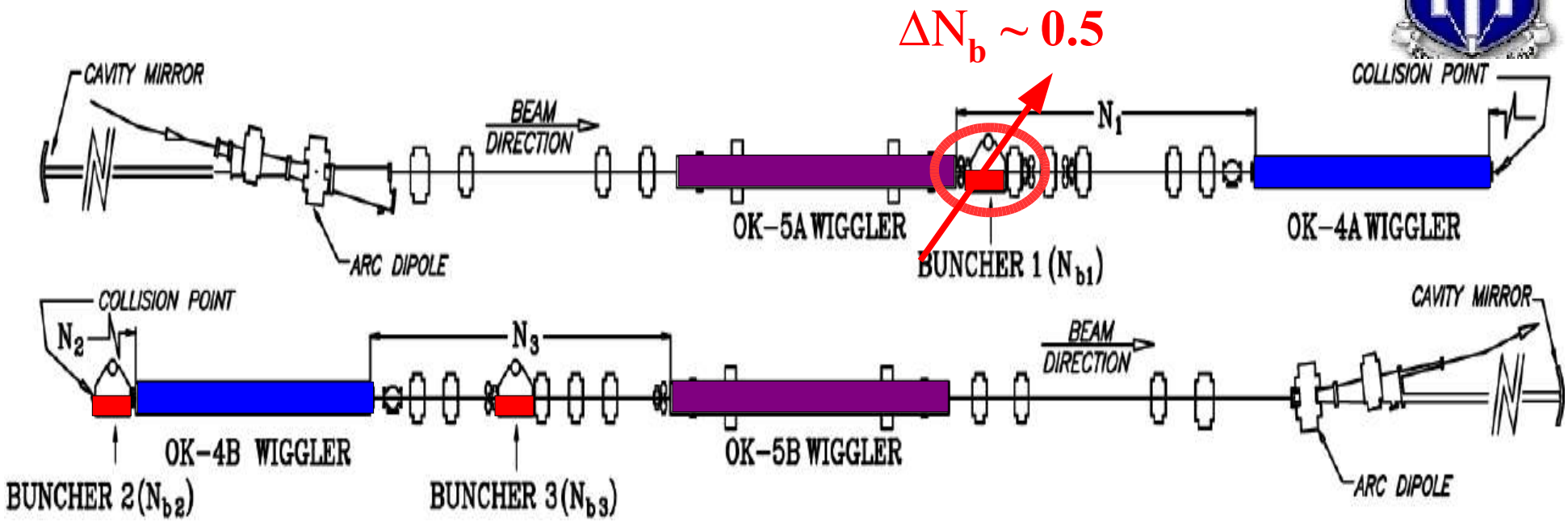
- **Microwave instability region: Gain ~ $I_b^{2/3}$**
- **DOK-1 gain ~2.2-2.3 times OK-4 gain + OK-5 gain**

DOK-1 FEL Detuning

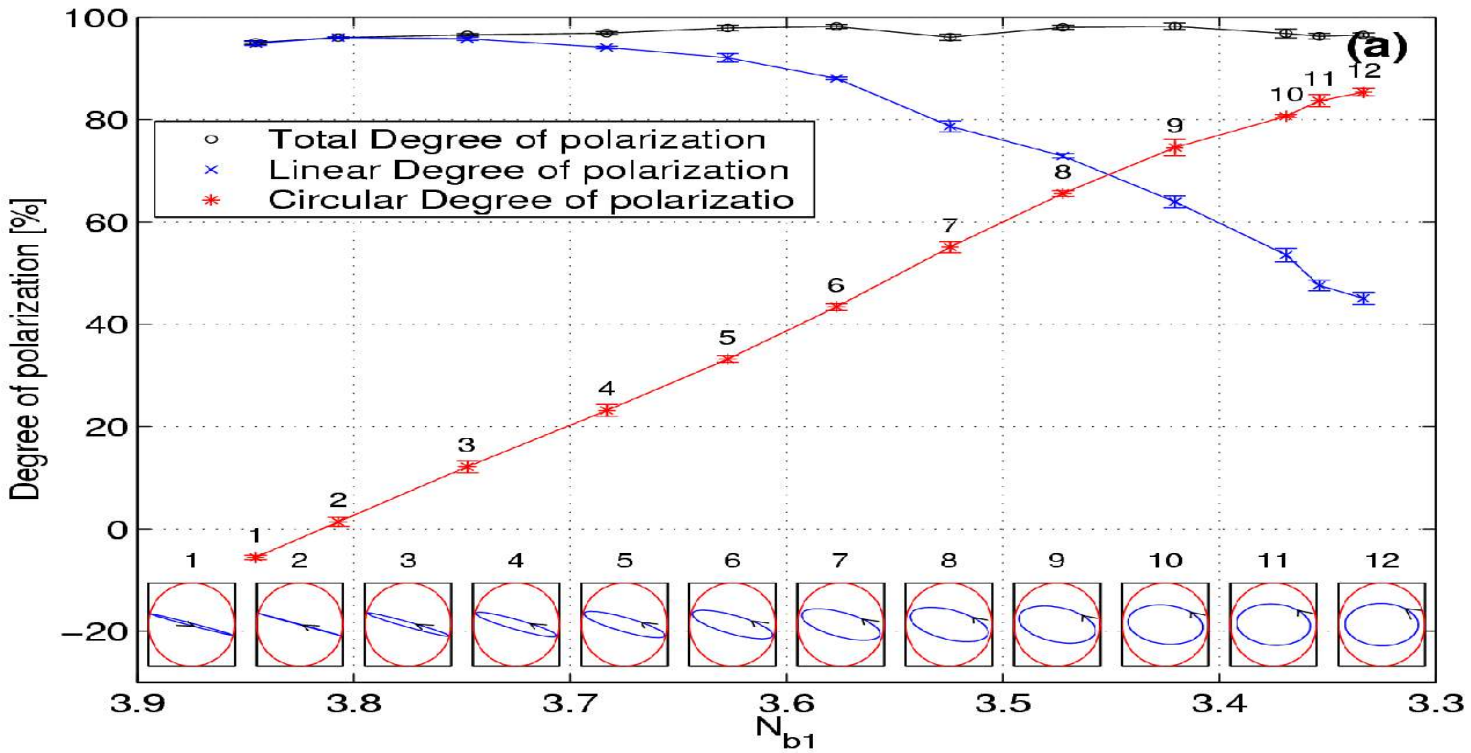




Switching FEL Polarization (One-Buncher Knob)

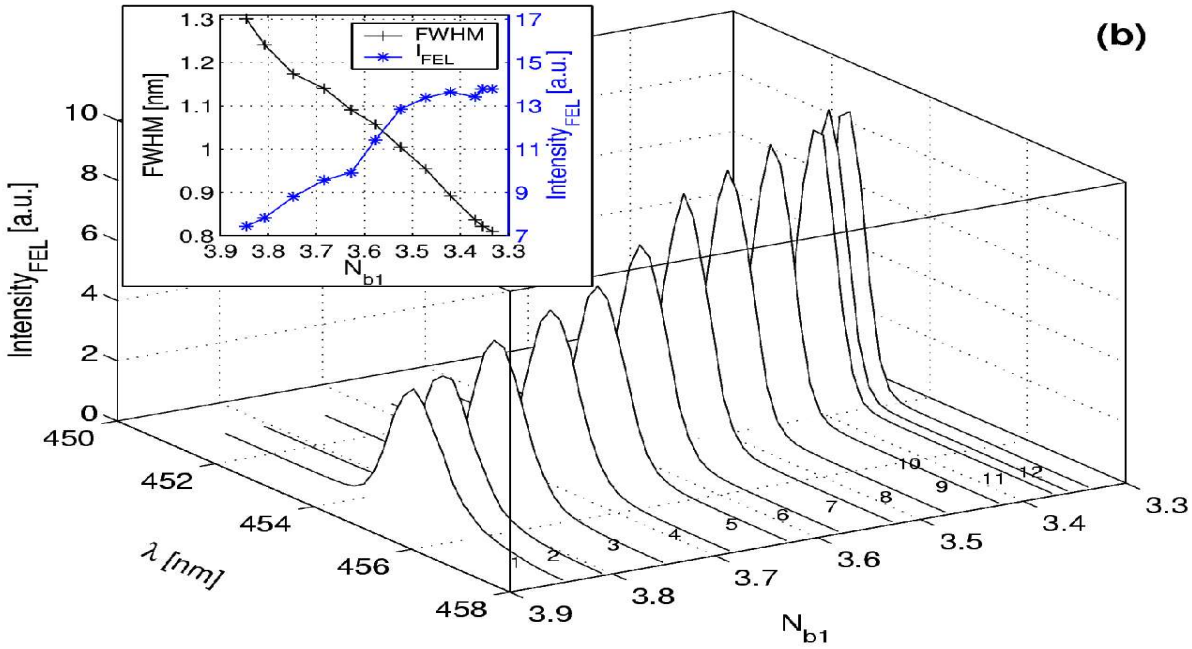


DOK-1 FEL Polarization Switch



- N_{b1} changes by 0.52 (from 3.85 to 3.33)

- Linear Pol: 95% to 45%
- Circular Pol: -6% to 85%
- Wavelength, λ, 455 to 453 nm
- Δλ, 1.30 nm to 0.81 nm
- Power increased by a factor of two



Kwang-Je Kim, *Circular polarization with crossed-planar undulators in high-gain FELs*, NIMA 445, 2000

DFELL, Duke University

CASA,

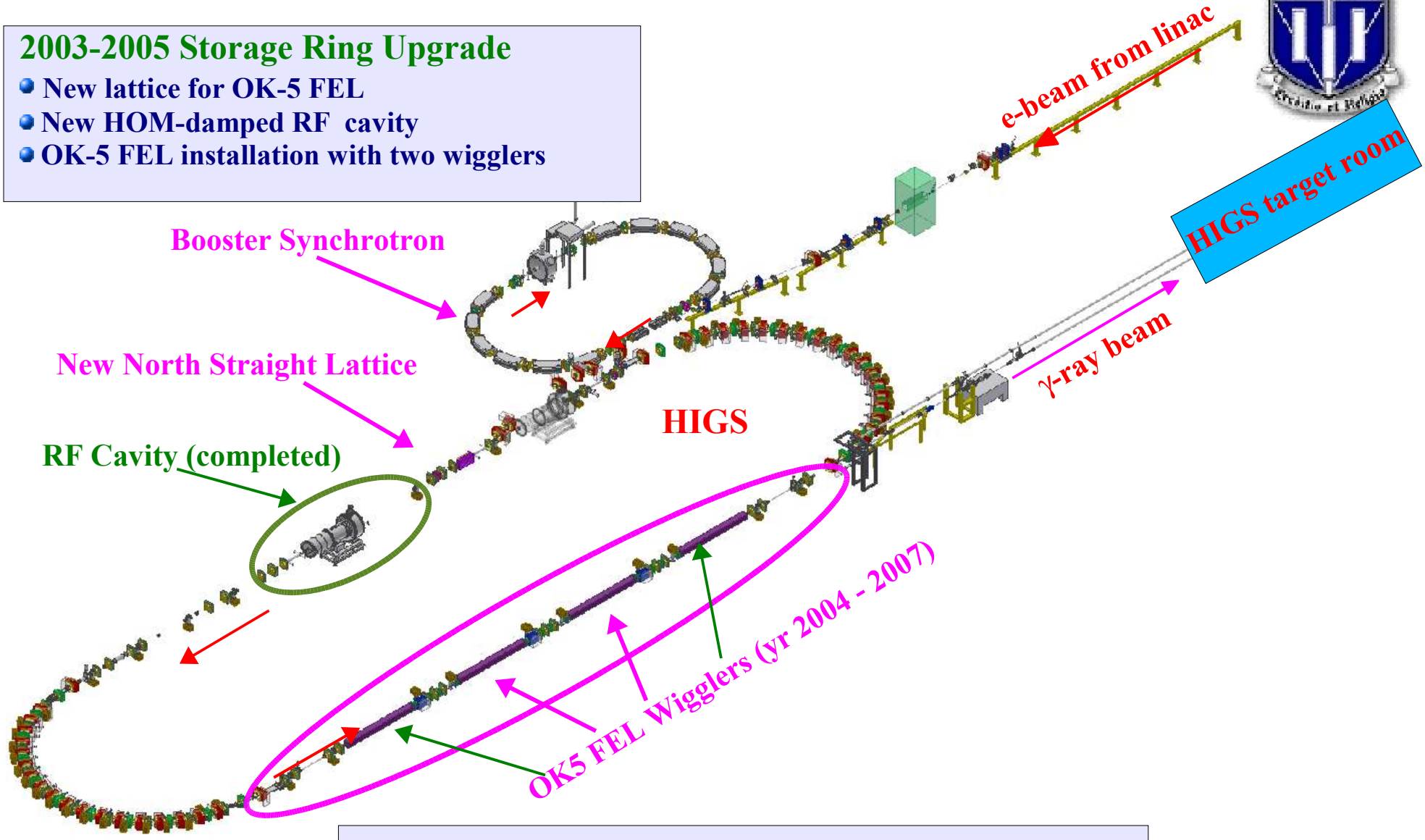
Near-Term Light Source Development

Booster Commissioning
Completing HIGS Upgrade with Four OK-5 Wigglers
Multi-color FEL Experiments

DFELL Facility after Full Upgrades in 2006

2003-2005 Storage Ring Upgrade

- New lattice for OK-5 FEL
- New HOM-damped RF cavity
- OK-5 FEL installation with two wigglers

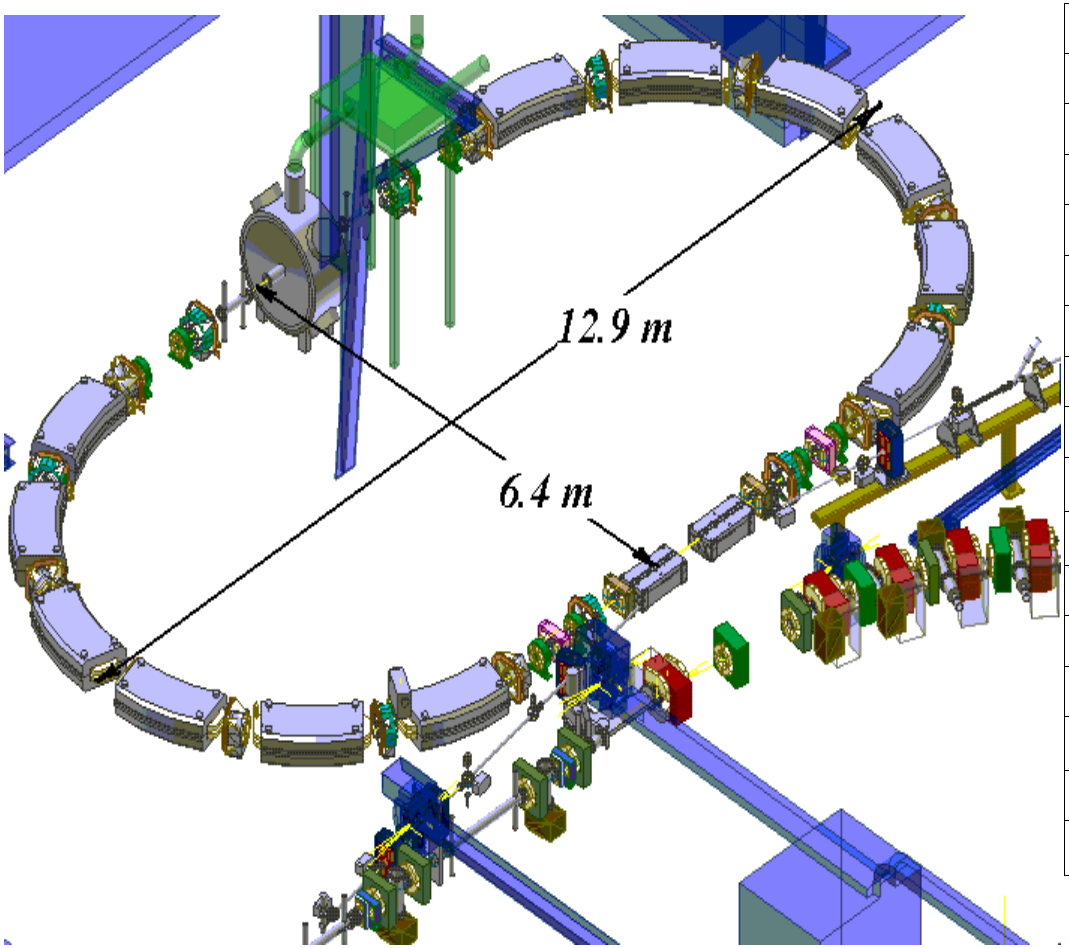


Fully Upgraded Facility (2006)

- Top-off injection, continuous gamma-ray operation
- Typical mode: 8-bunch, 20 mA/bunch

HIGS Booster Ring: *a Full Energy Injector*

- **0.27 – 1.2 GeV booster synchrotron**
- **31.9 m, 100 mA (max), up to 19 bunches**
- **Cycle time: 1.2 sec (single bunch), 2.5 sec (multi-bunch)**

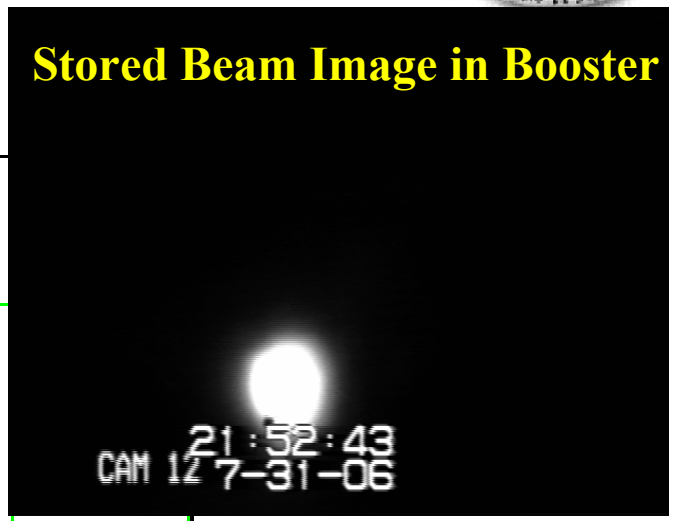


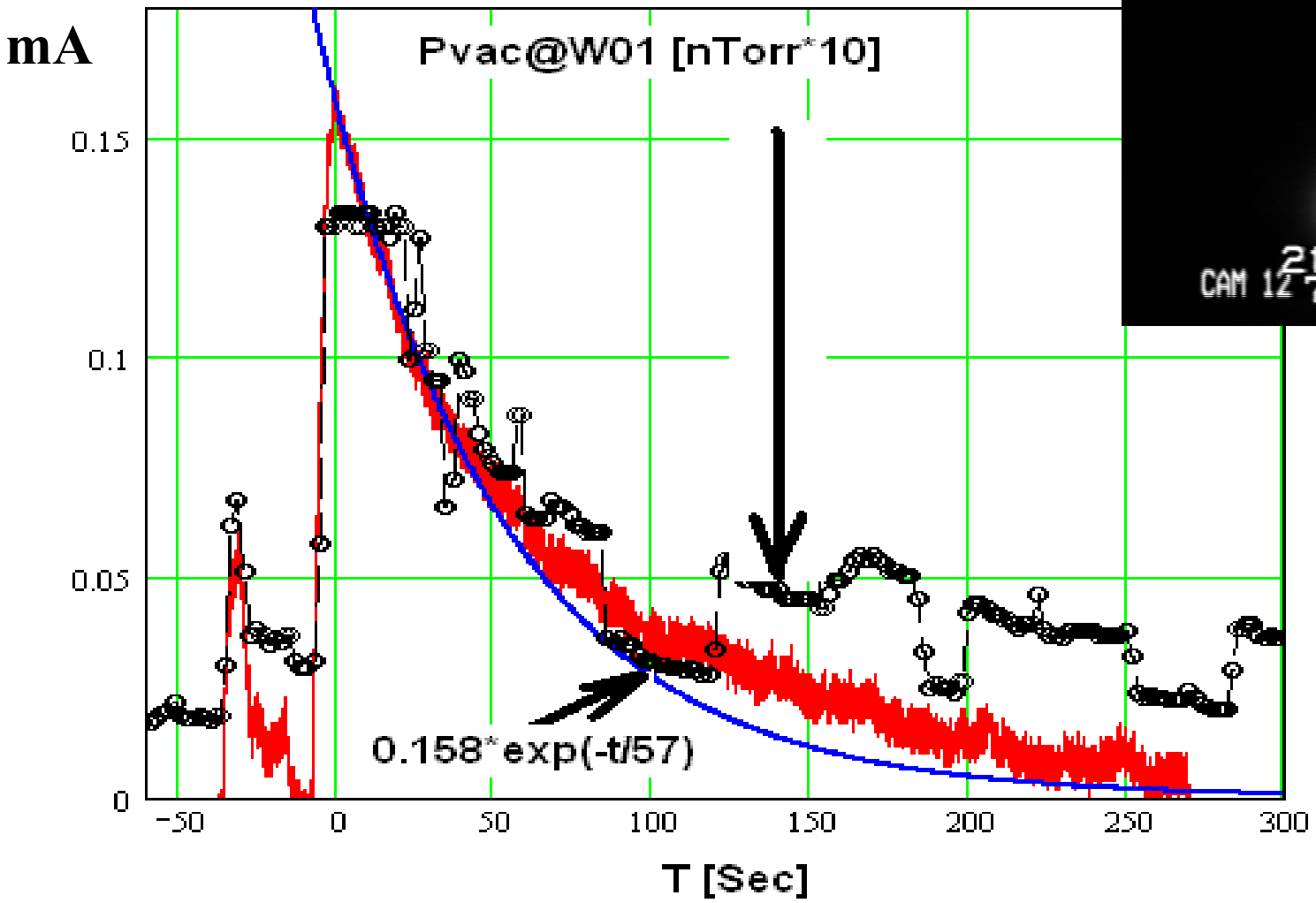
Injection energy [GeV]	0.27
Maximum energy [GeV]	1.2
Max beam current [mA]	100
Circumference [m]	31.902
Bending radius [m]	2.273
RF frequency [MHz]	178.55
Harmonic number	19
Operation cycle [sec]	2.5
Min Energy risetime [sec]	0.5–0.8
Emittance ε_x, ε_y [nm·rad]	350/ 15
Maximum $\beta_x/\beta_y/\eta_x$ [m]	25.4/9.4/1.4
Betatron tunes Q_x/Q_y	2.43/0.46
Momentum compaction	0.153
Natural chromaticity C_x/C_y	-1.7/ 3.7
Damping time $\tau_{x,y}/\tau_s$ [mS]	3.16 /1.58
Energy loss/turn [KeV]	80.7
Energy spread	$6.8 \cdot 10^{-4}$

HIGS Booster Ring Commissioning

As of Aug. 15, 2006

- **Stored 0.65 mA into the booster at 270 MeV**
- **Attempted ramping to 400 MeV**
- **Beam lifetime: few minutes**





Summary

- **Challenges for Duke FELs**
  - Dynamics degradation due to OK-5 wigglers (reduced lifetime)
  - Full control of multiple collision points for gamma production
  - Mirror damages due to radiation
  - Improving the FEL power for user operation
- **Key thrusts for DOK FELs in the near future**
  - VUV operation between 150 and 200 nm

(For DOK1 FEL, 20-30% gain expected for 150 nm with I_b =40-50 mA)

  - Fast polarization switches

Horizontal + Vertical -> Circular; Left + Right -> Linear

  - Multi-color operation