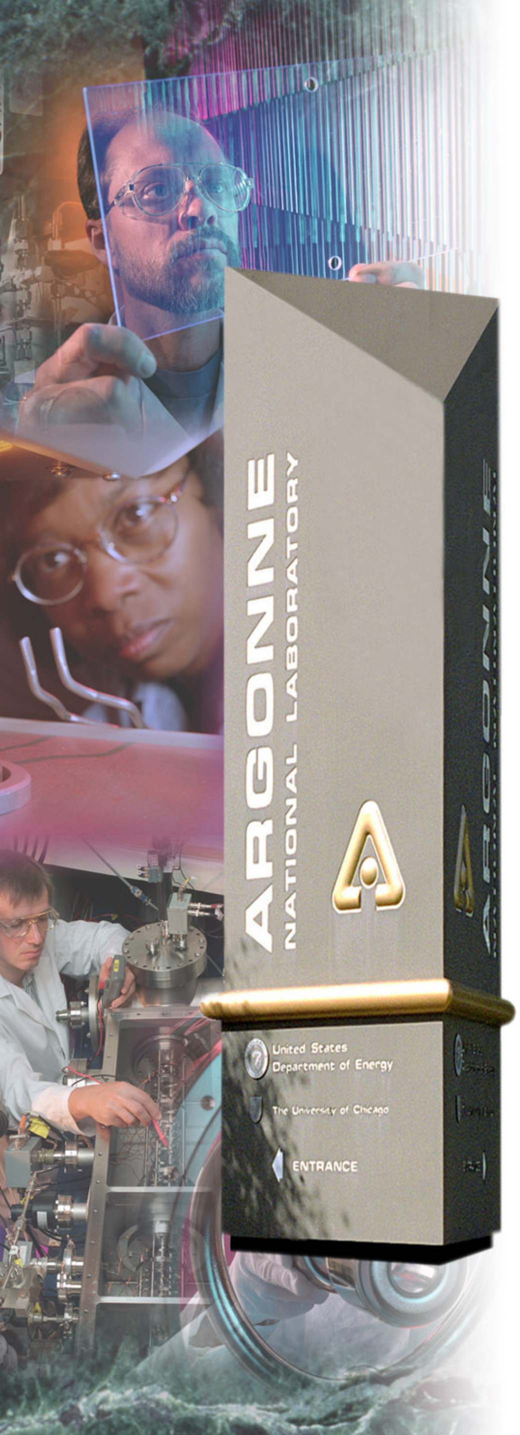

An experimental study of the beam-steering effect on the FEL Gain at LEUTL's segmented undulators

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J. Lewellen, S. Milton

Presented at the 26th International FEL Conference

Argonne National Laboratory

Office of Science
U.S. Department of Energy

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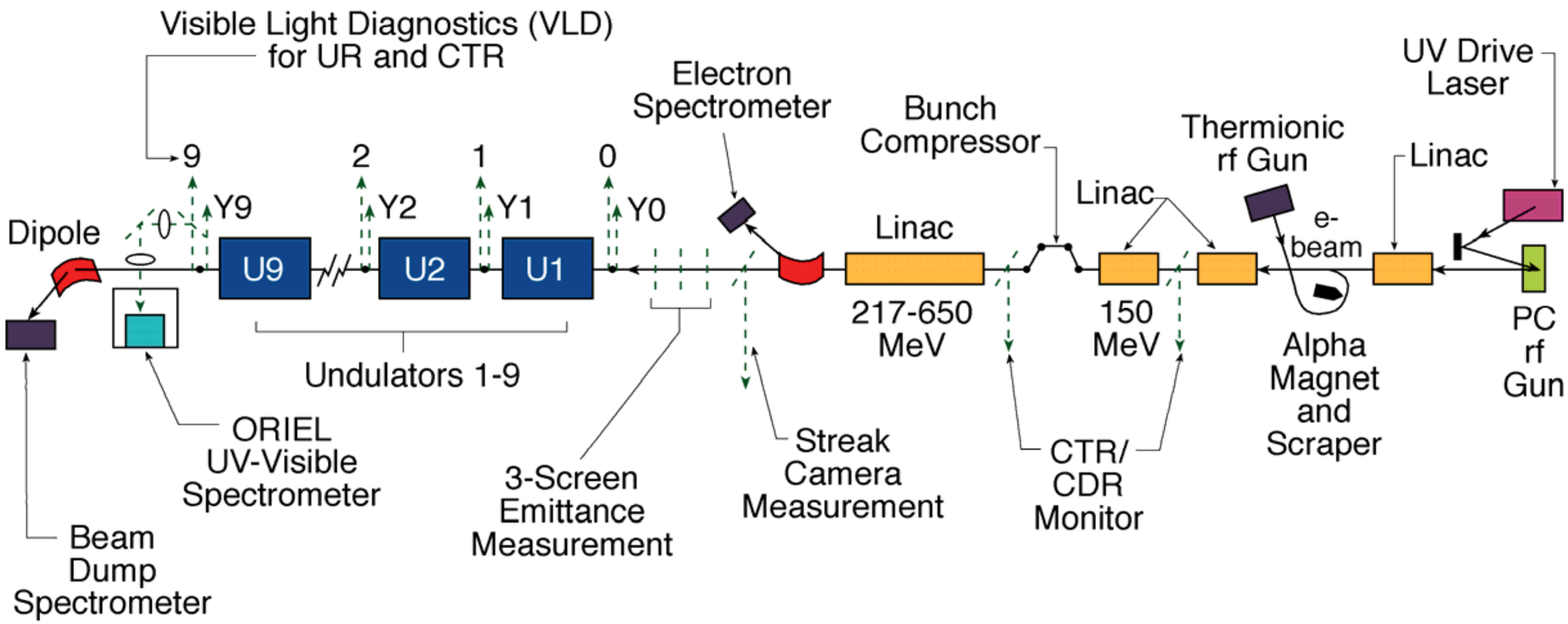
Office of Science Laboratory
Operated by The University of Chicago

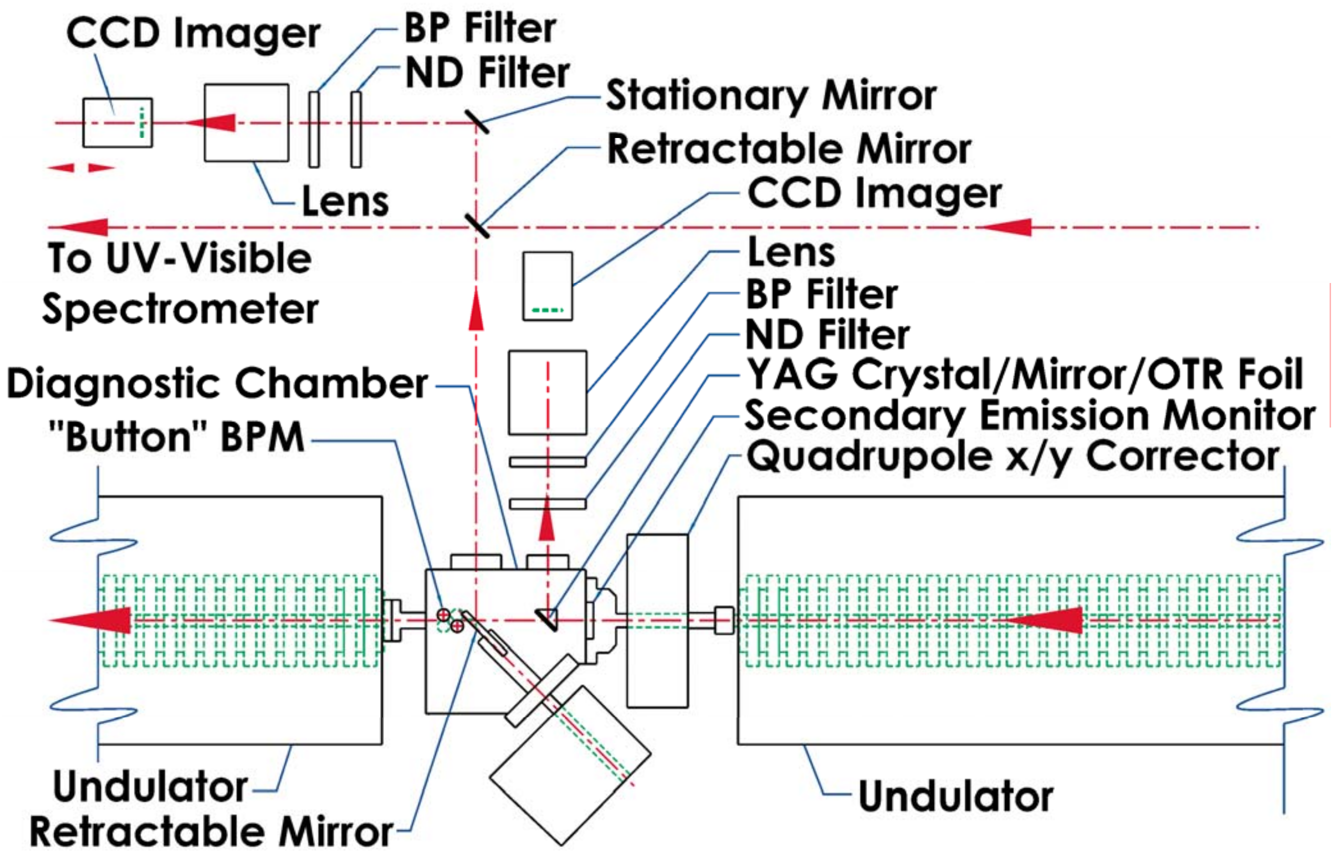
Motivation

- **T. Tanaka, et al., "Consideration on an Alignment Tolerance of BPMs for SCSS Undulator Line," FEL 2003 Conference**
  - Showed that trajectory error can be more serious in degrading FEL performance than undulator field errors
  - Considered Single-Kick-Error (SKE) Effect
  - Derived a formula in the remarkably simple form ➔ **easy to apply and useful!**
- **Verify Tanaka's analytical model by experiments and simulations at the APS's LEUTL facility; this may help to understand the orbit effects on FEL performance quantitatively.**

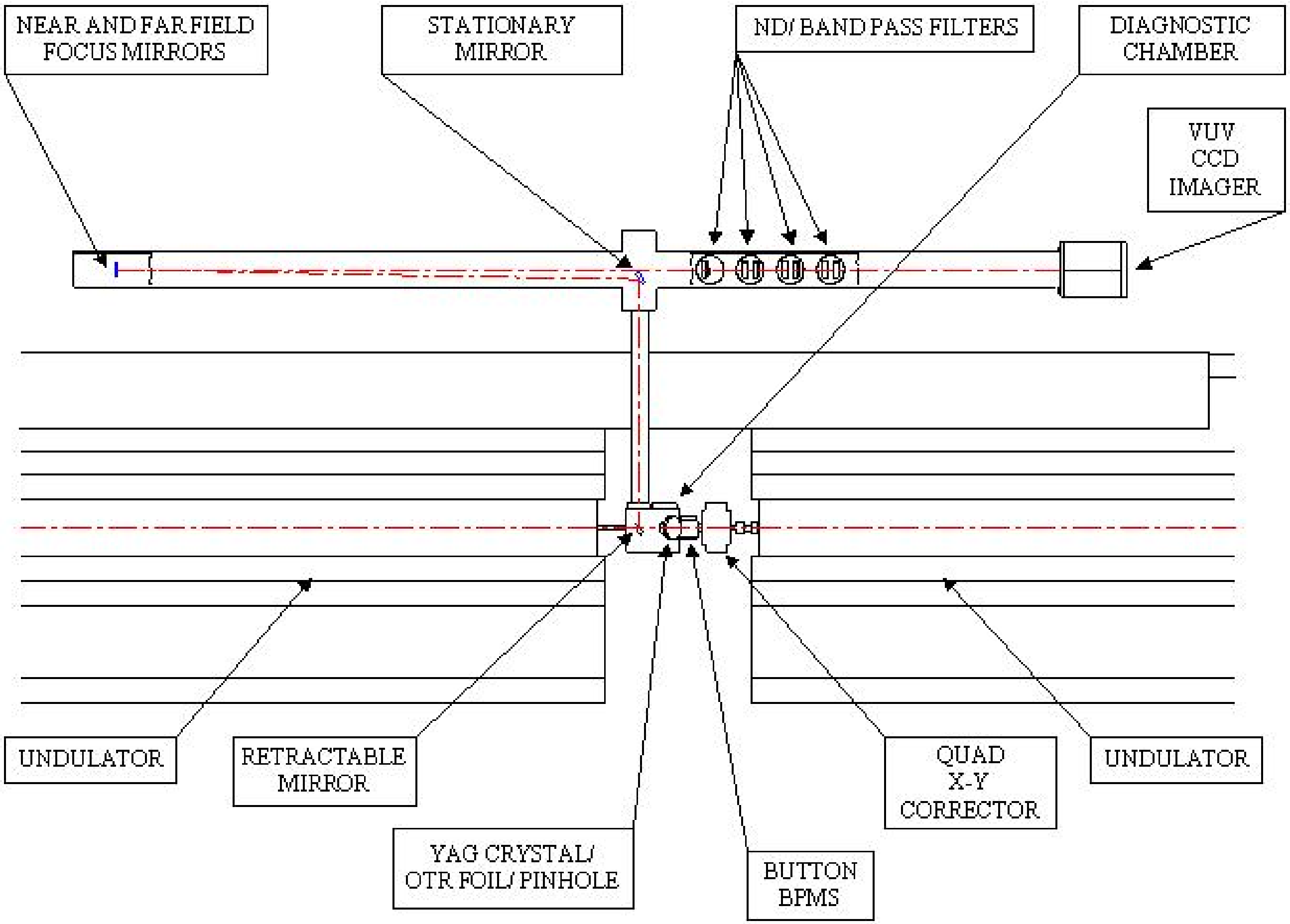
The APS SASE FEL Schematic



LEUTL FEL Diagnostic Station Schematic



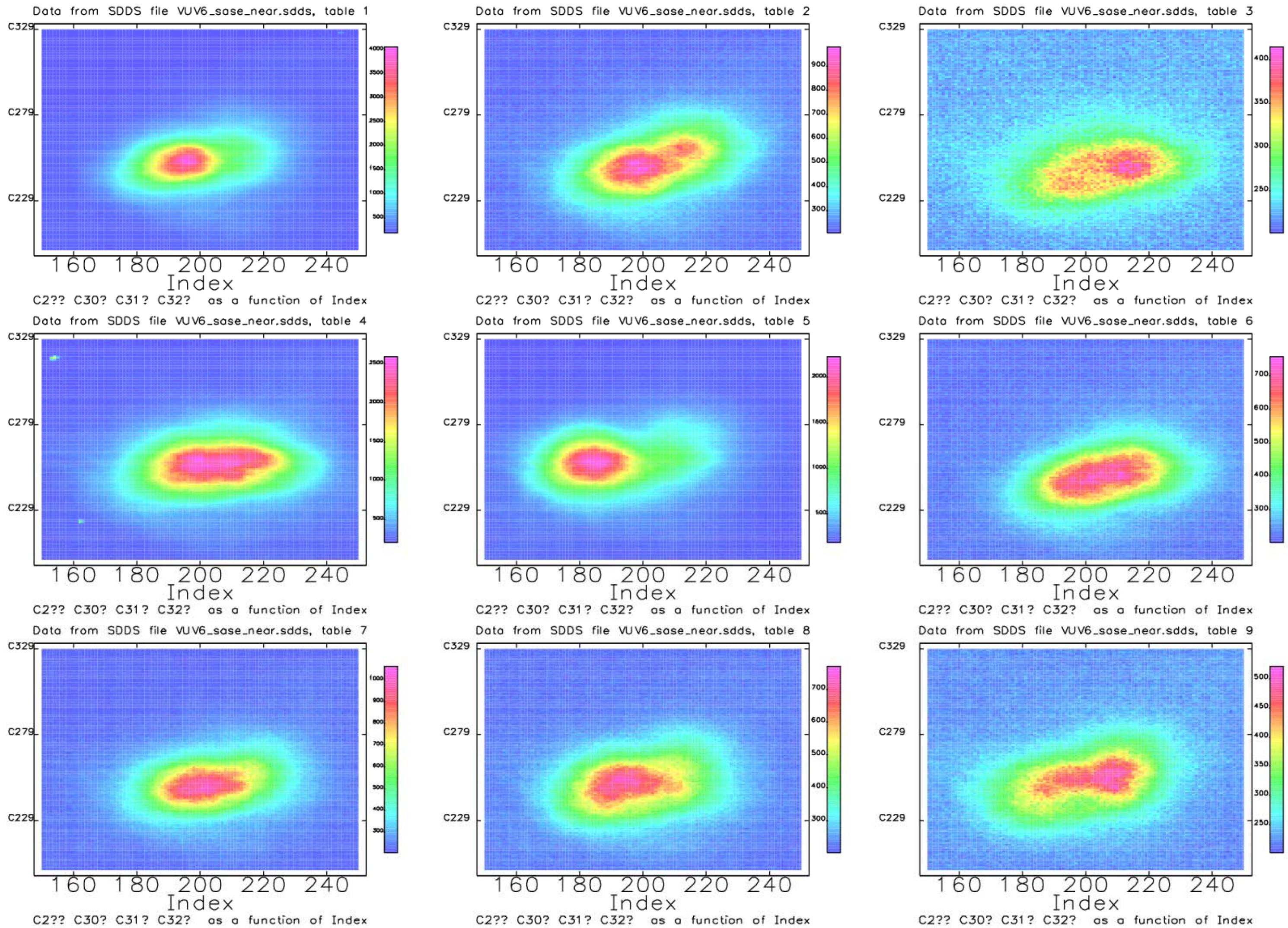
LEUTL FEL Diagnostic Station Schematic (2)



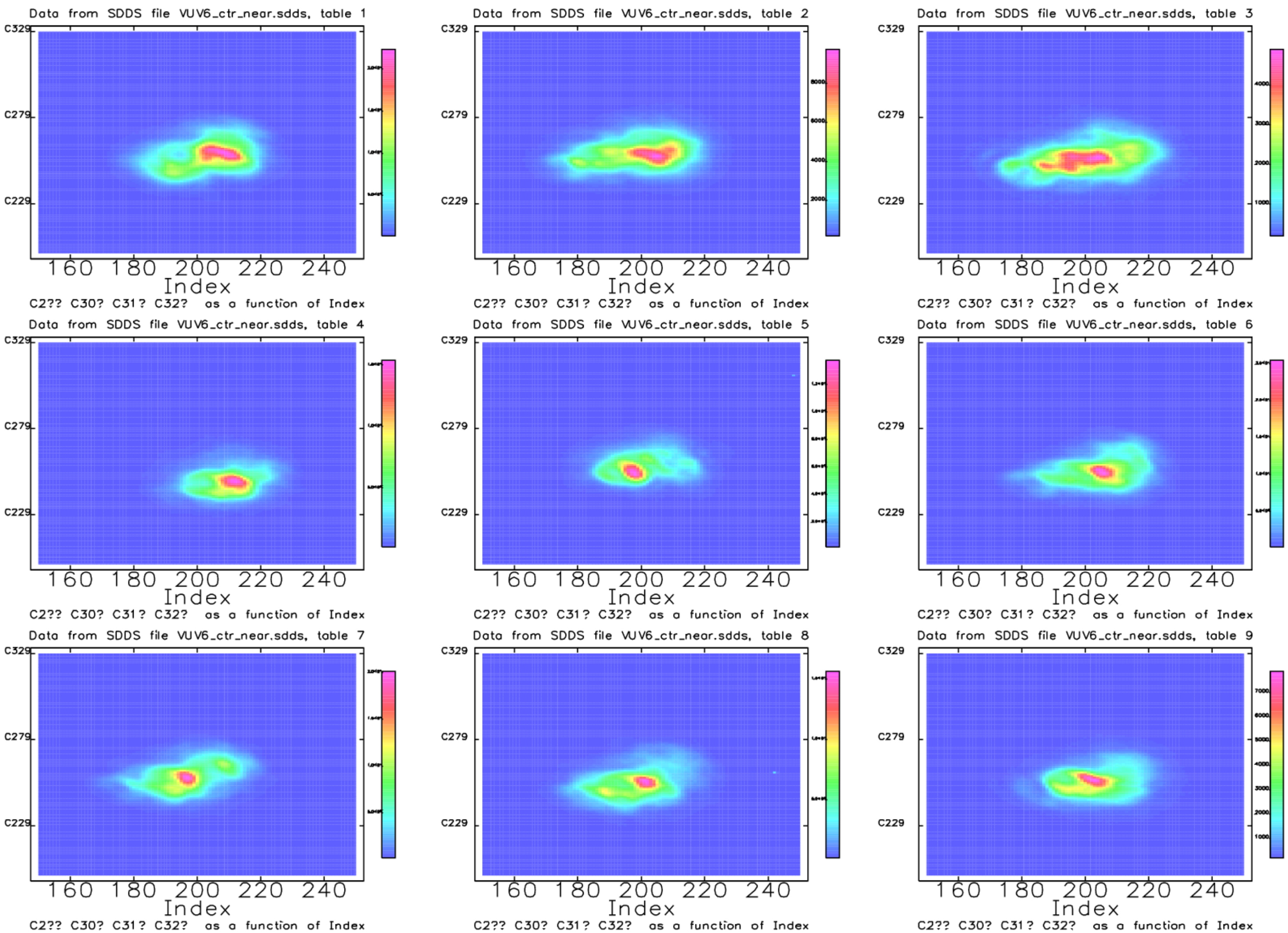
Initial Experimental Setup

- **Measured e-beam parameters**
  - E=439 MeV ➔ λs=130 nm
  - Q=250 pC, FWHM=250 fs ➔ Ipeak=940 A
  - Emittance=4.5/3.5 π mm-mrad
  - ΔE/E=0.15 %
- **Established a reference orbit**
  - Undulator radiation near- and far-field image ➔ gain measurement
  - Coherent optical transistion radiation: near- and far-field images ➔ micro-bunching and e-beam position

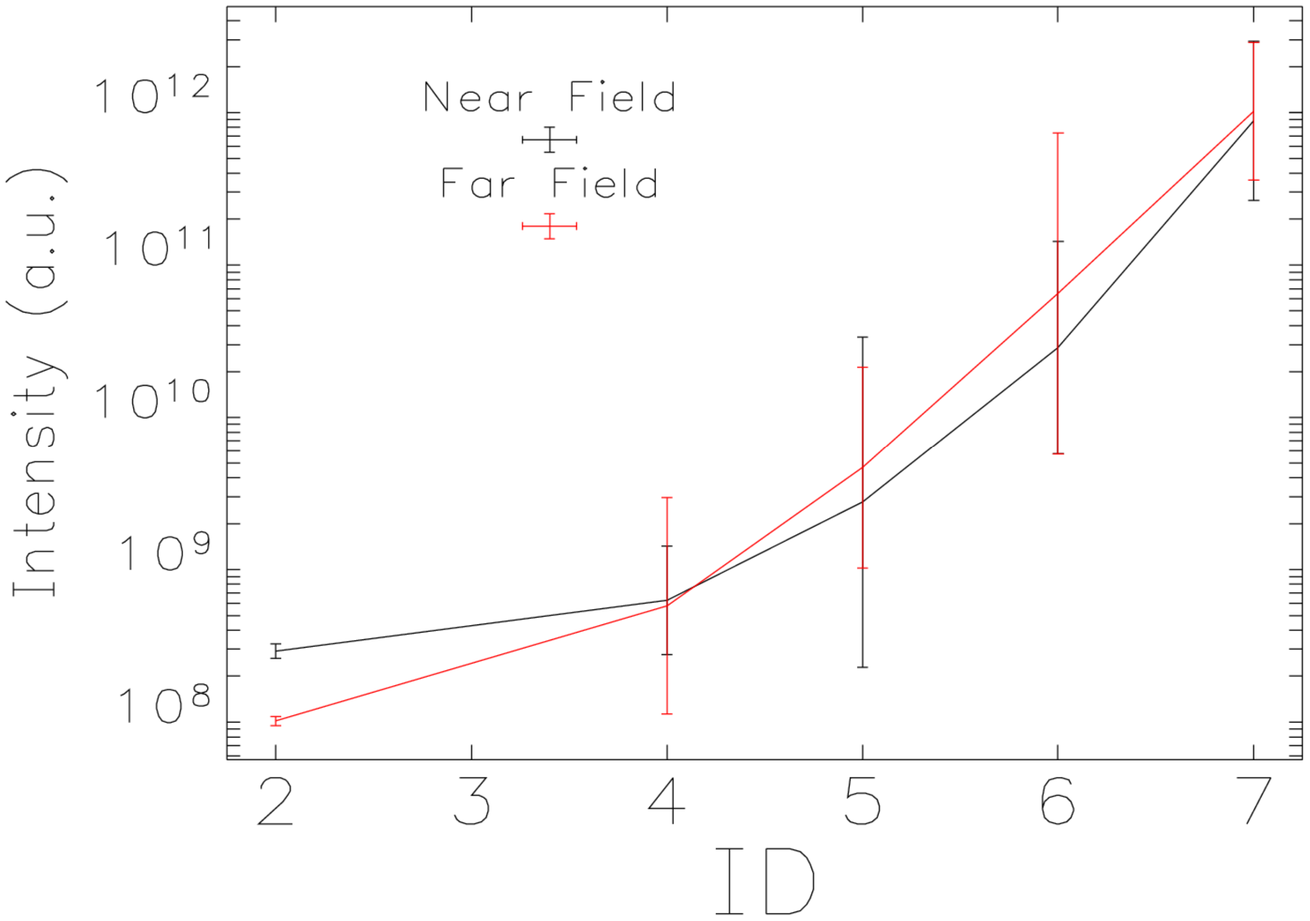
Undulator Radiation (UR): VUV-6



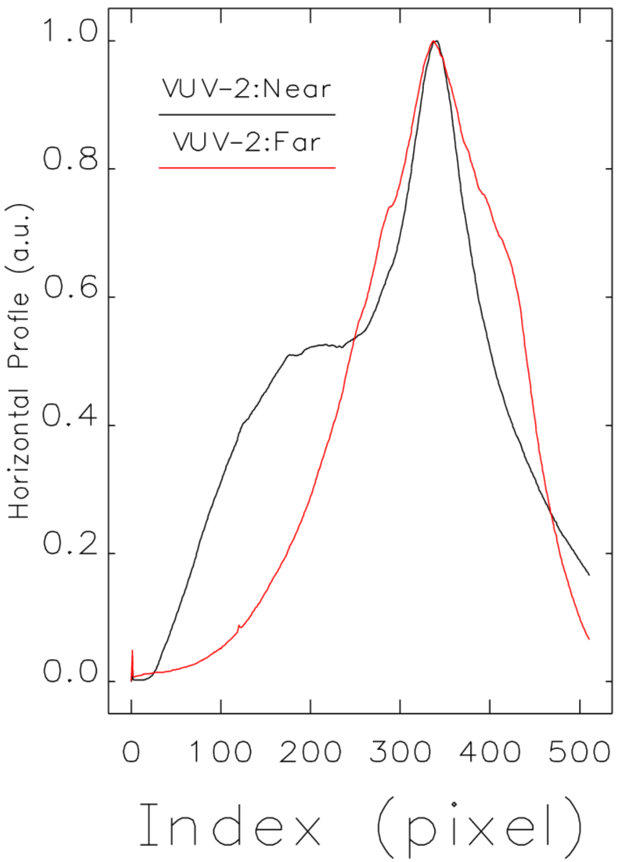
Coherent Optical Transition Radiation (COTR): VUV-6



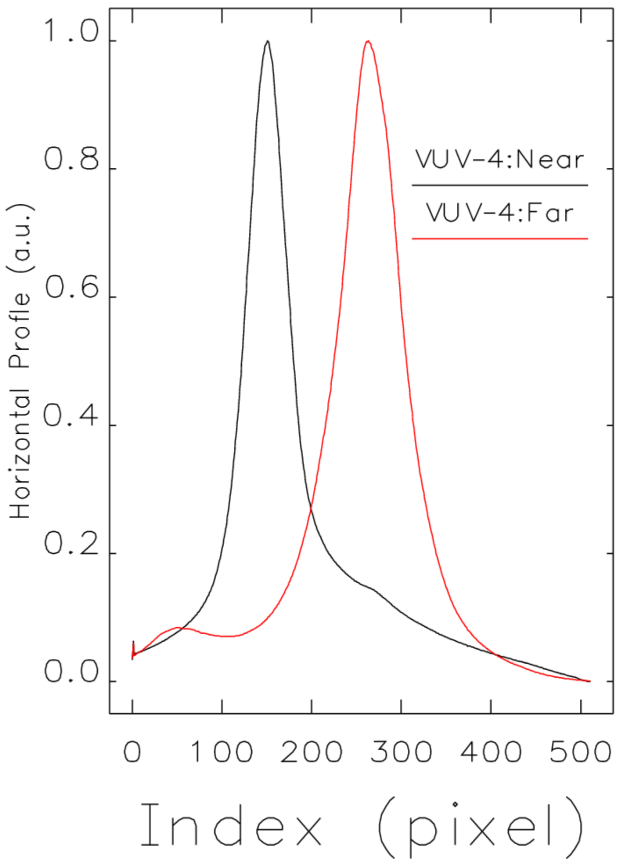
Gain Measurement: near-field and far-field



Near-field vs. Far-field

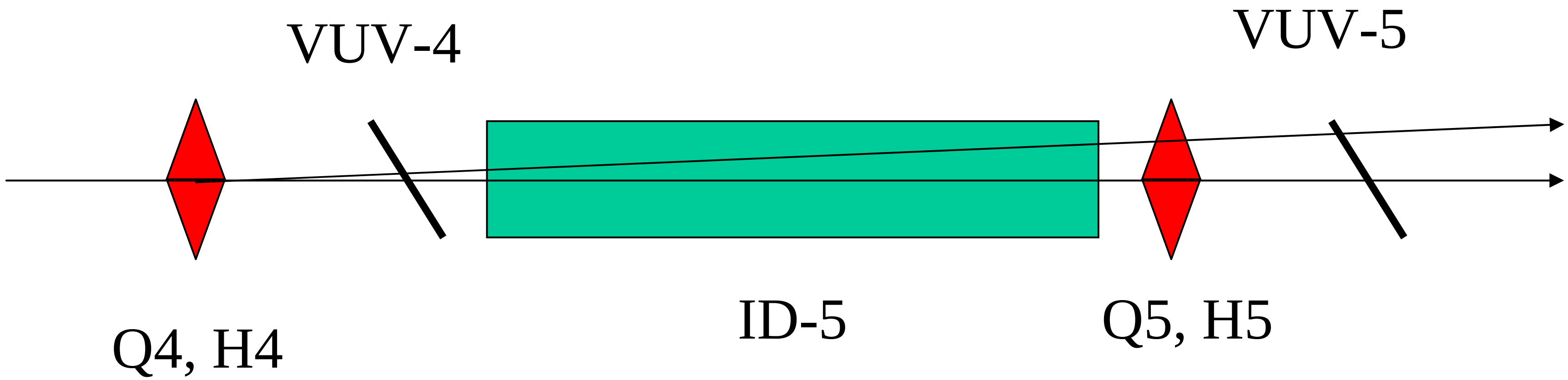


VUV-2



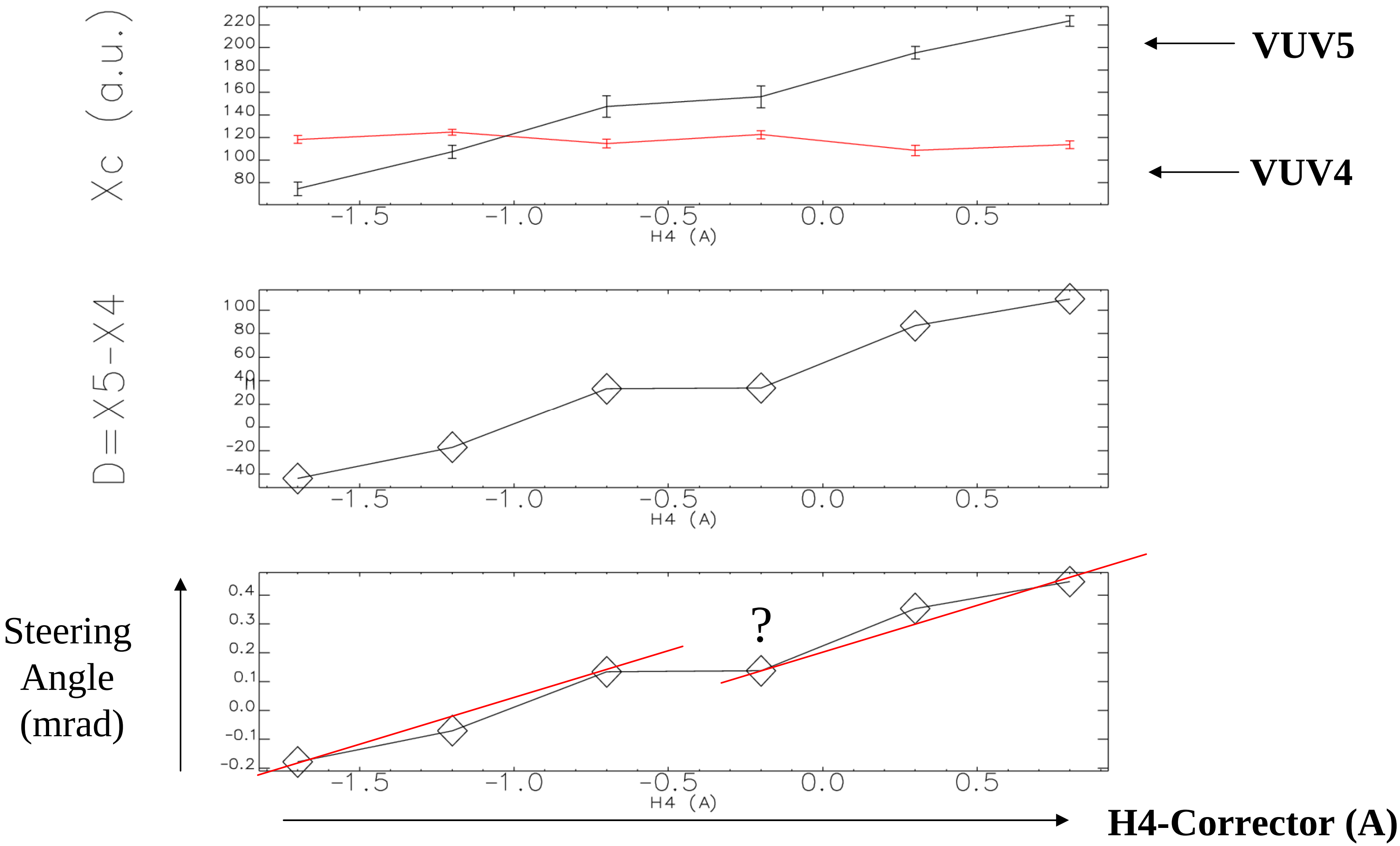
VUV-4

Single-Kick-Error (SKE) Experiment: Configuration

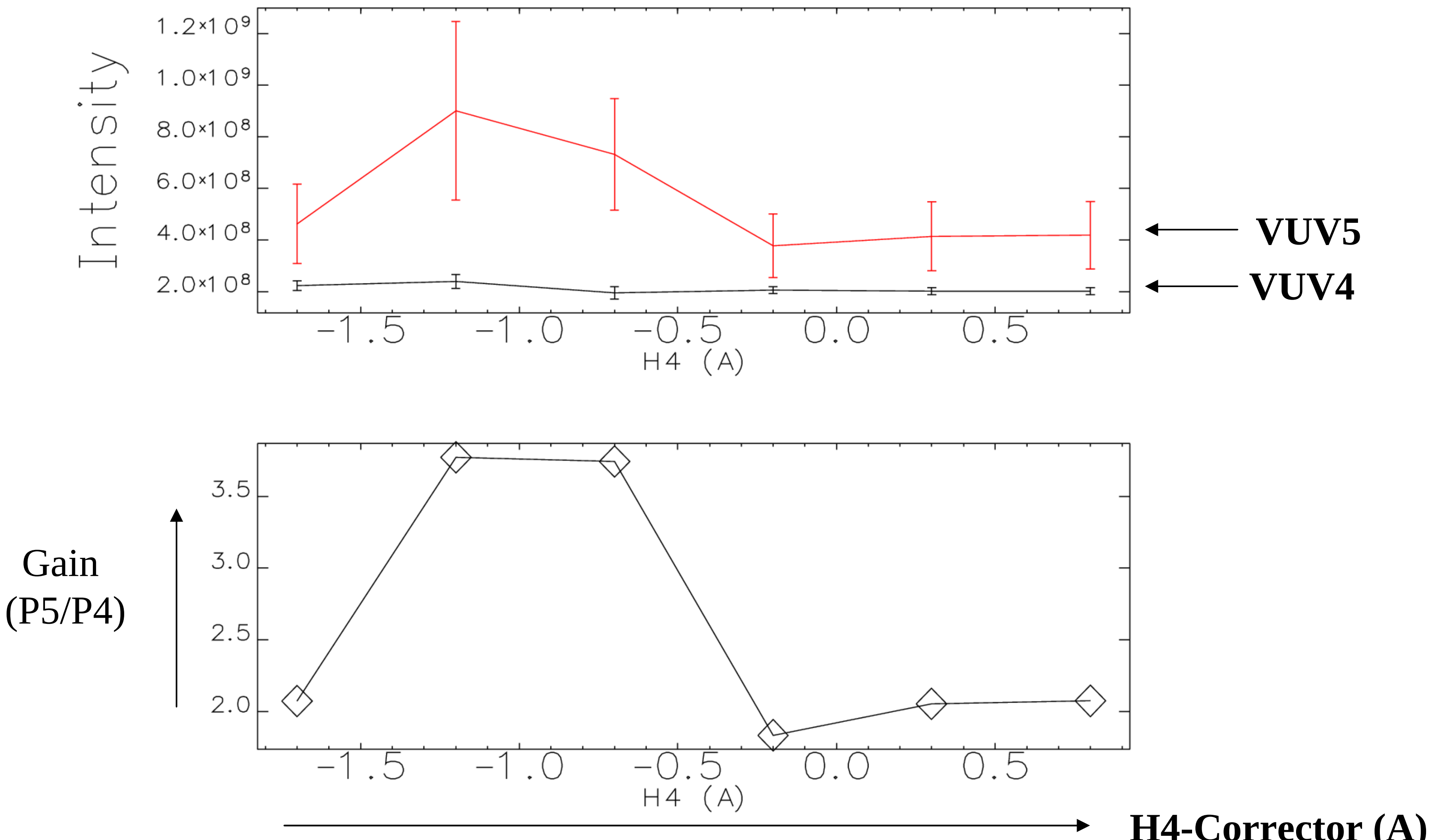


1. Turn Off Q5, H5
2. Vary H4
3. Observe COTR at VUV-4 and VUV-5 ➔ Angle = (X5-X4)/L
4. Observe UR at VUV-4 and VUV-5 ➔ Gain = P5/P4

SKE Experiment: e-Beam (x-position)



SKE Experiment: Intensity



Fit Formula: Tanaka's Model Equation

1. Critical Angle

$$\theta_c = \sqrt{\lambda / L_g}$$

L_g=gain length of ideal orbit,
Unknown parameter to be determined

2. Gain Length of Kicked Orbit

$$L_g^{'}(x) = \frac{L_g}{1 - x^2}$$

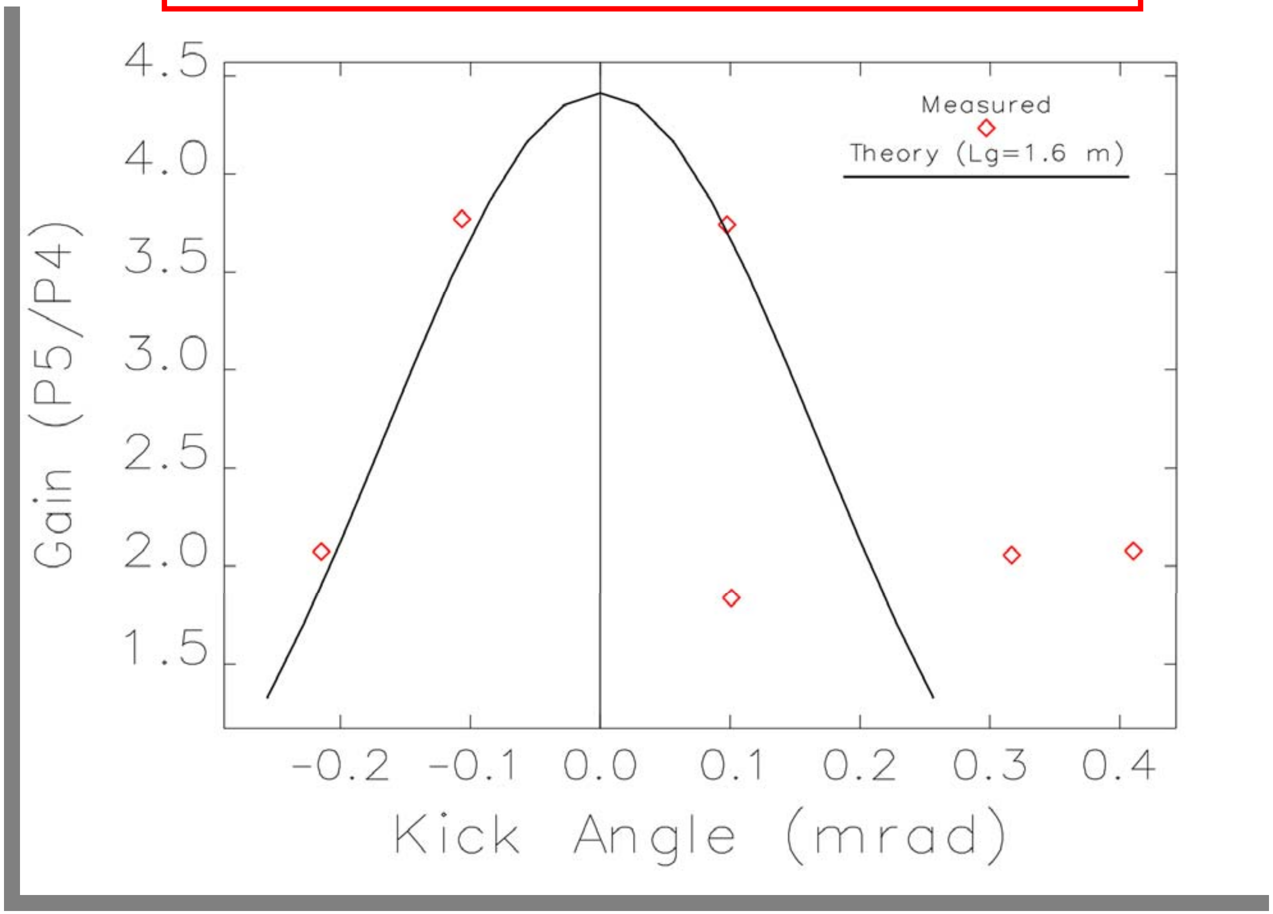
$x=\theta/\theta_c$; θ=kick angle.

3. Fit Parameter: L_g

$$Gain(x;Z) = \frac{P(x;Z)}{P_0} = \exp\left[\frac{Z}{L_g^{'}(x)}\right]$$

Experiment vs. Theory

L_g (Ideal Orbit) = 1.6 m !
(Critical Angle = 0.285 mrad)



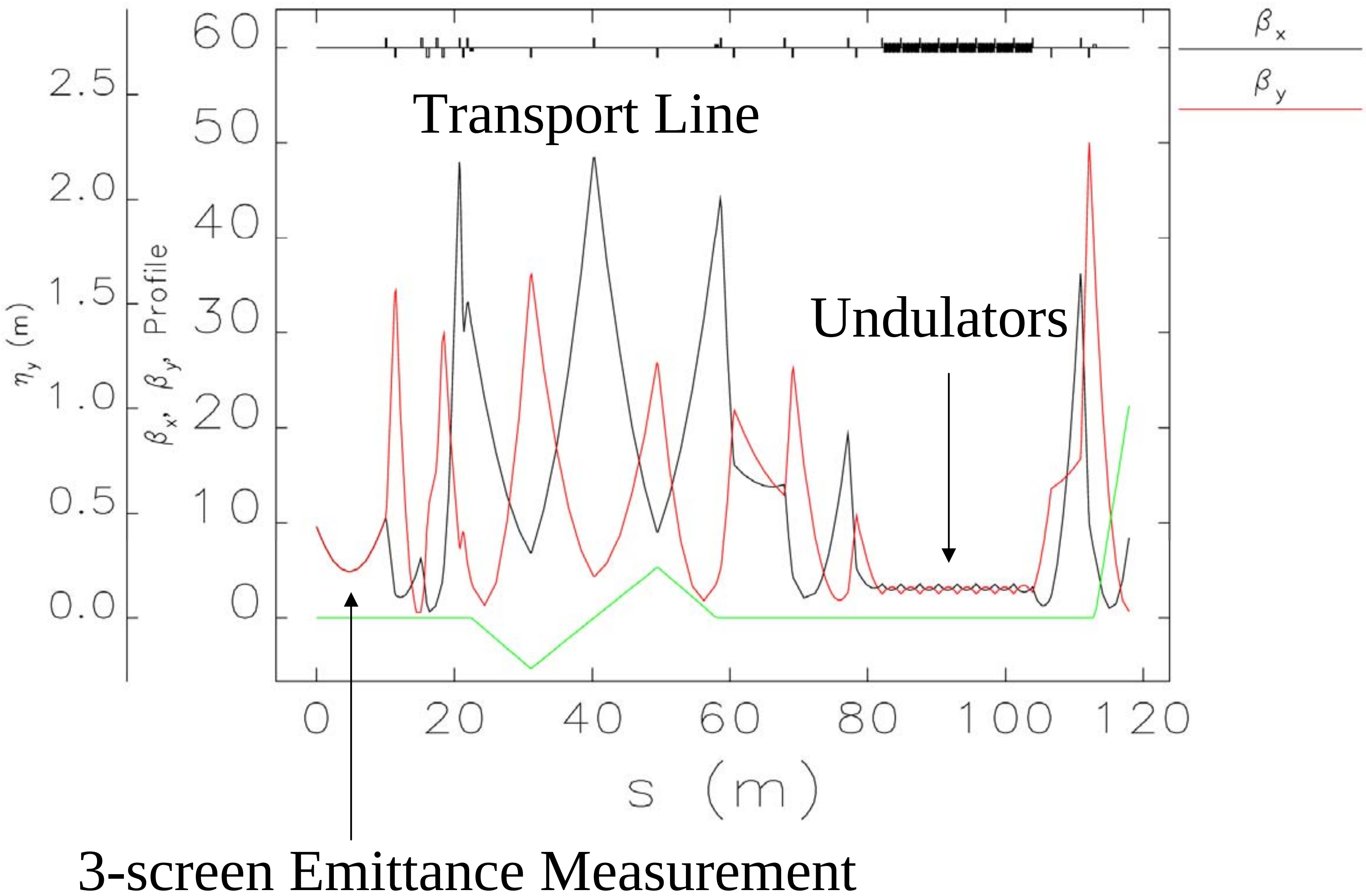
Next Step: Comparison with Simulation

- **Simulation Program: GENESIS 1.3**

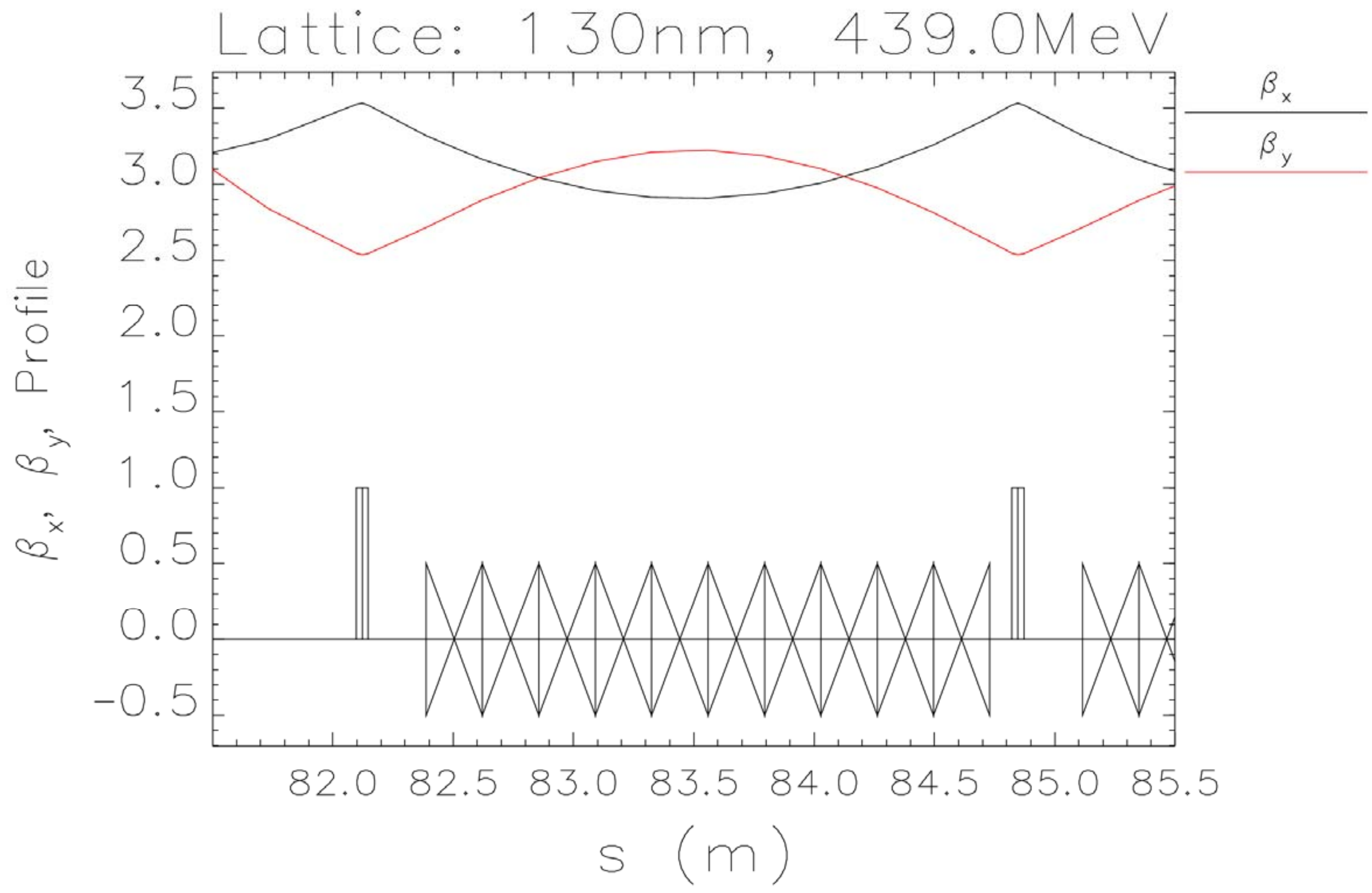
- **Nominal simulation parameter**
  - λs=130 nm,
  - E=439 MeV, $\Delta E/E$=0.15 %
  - Ip=600 A, FWHM=250 fs
  - Emittance=4.5/3.5 π mm-mrad

- **Find the simulation condition for Lg = 1.6 m !**
  - **Vary Ip**

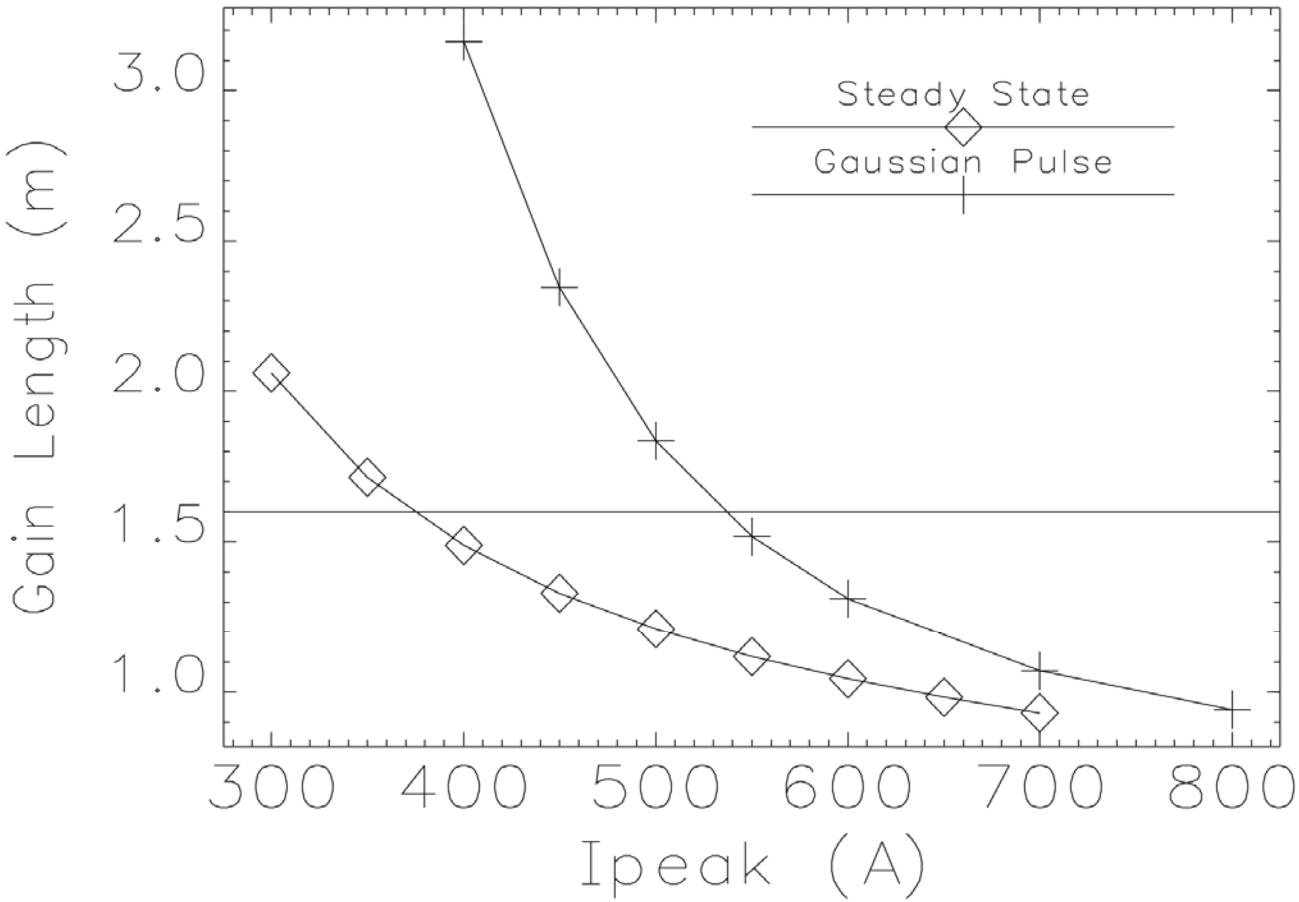
LEUTL Lattice: *Lattice parameters from elegant calculation*



In GENESIS we only simulate segmented undulators with quad+corrector



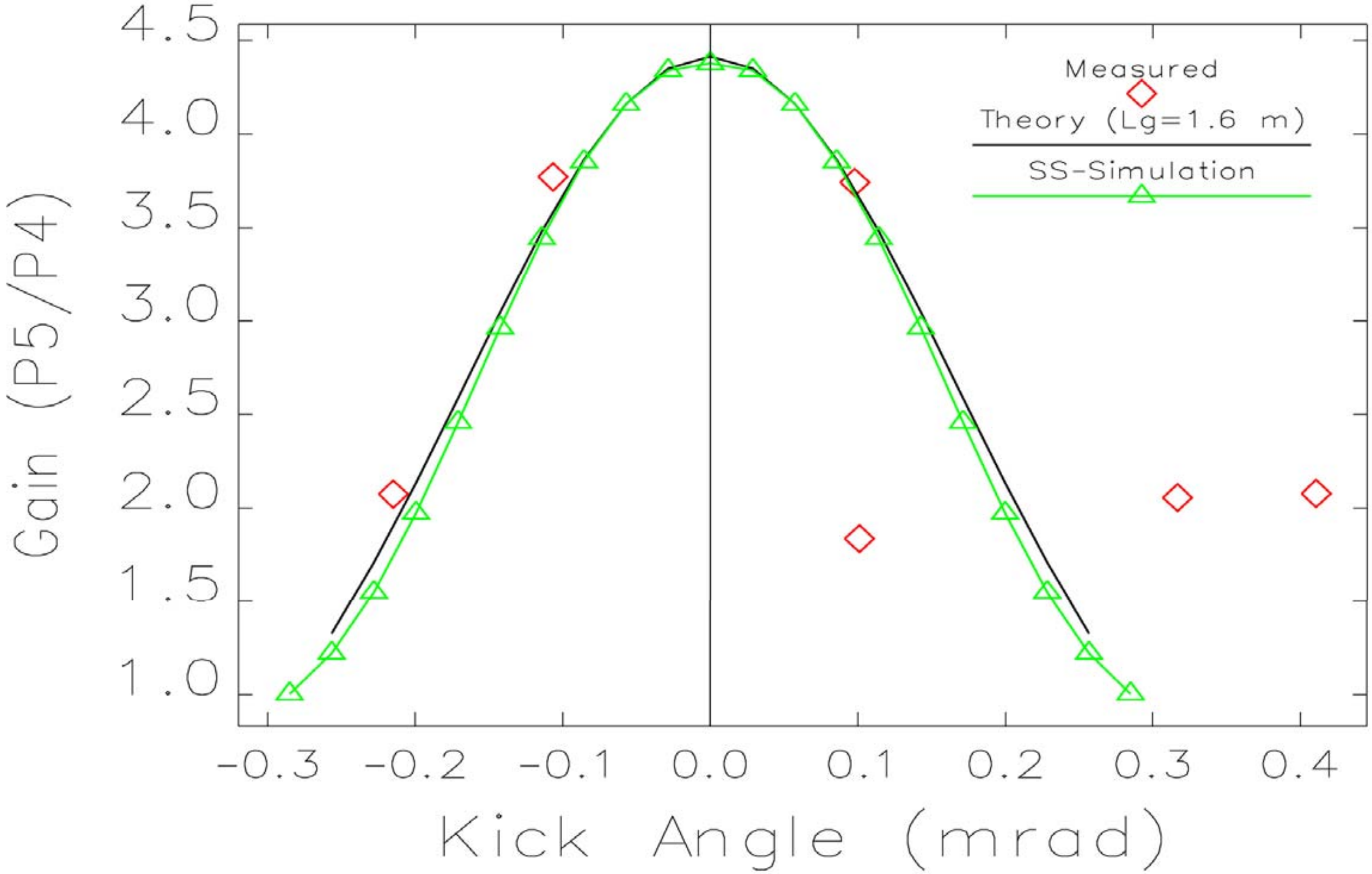
Find Beam Condition for Lg=1.6m



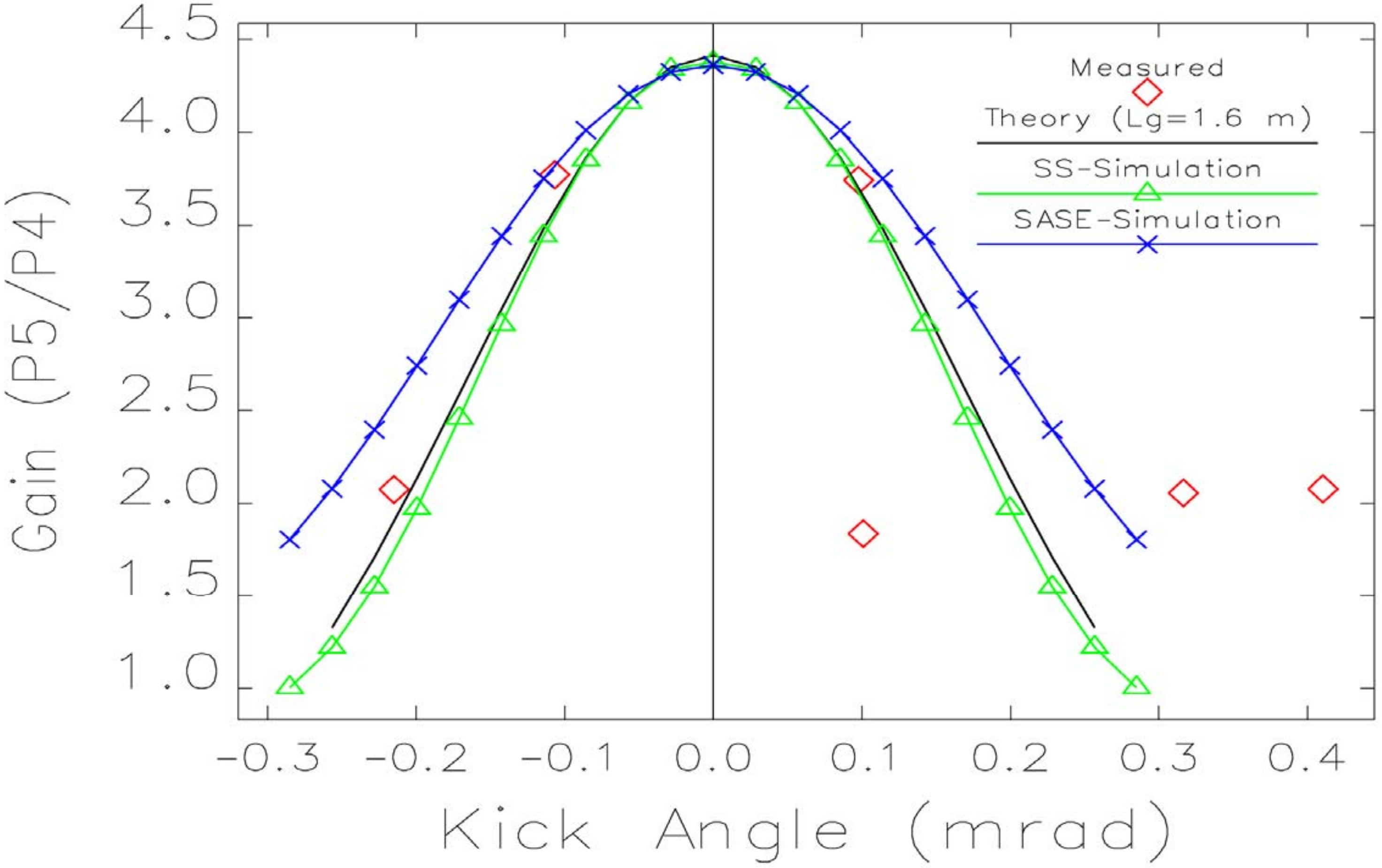
Ip = 380 A
for Steady State

Ip= 540 A
for 250 fs
FWHM pulse

Simulation Result: Steady-State



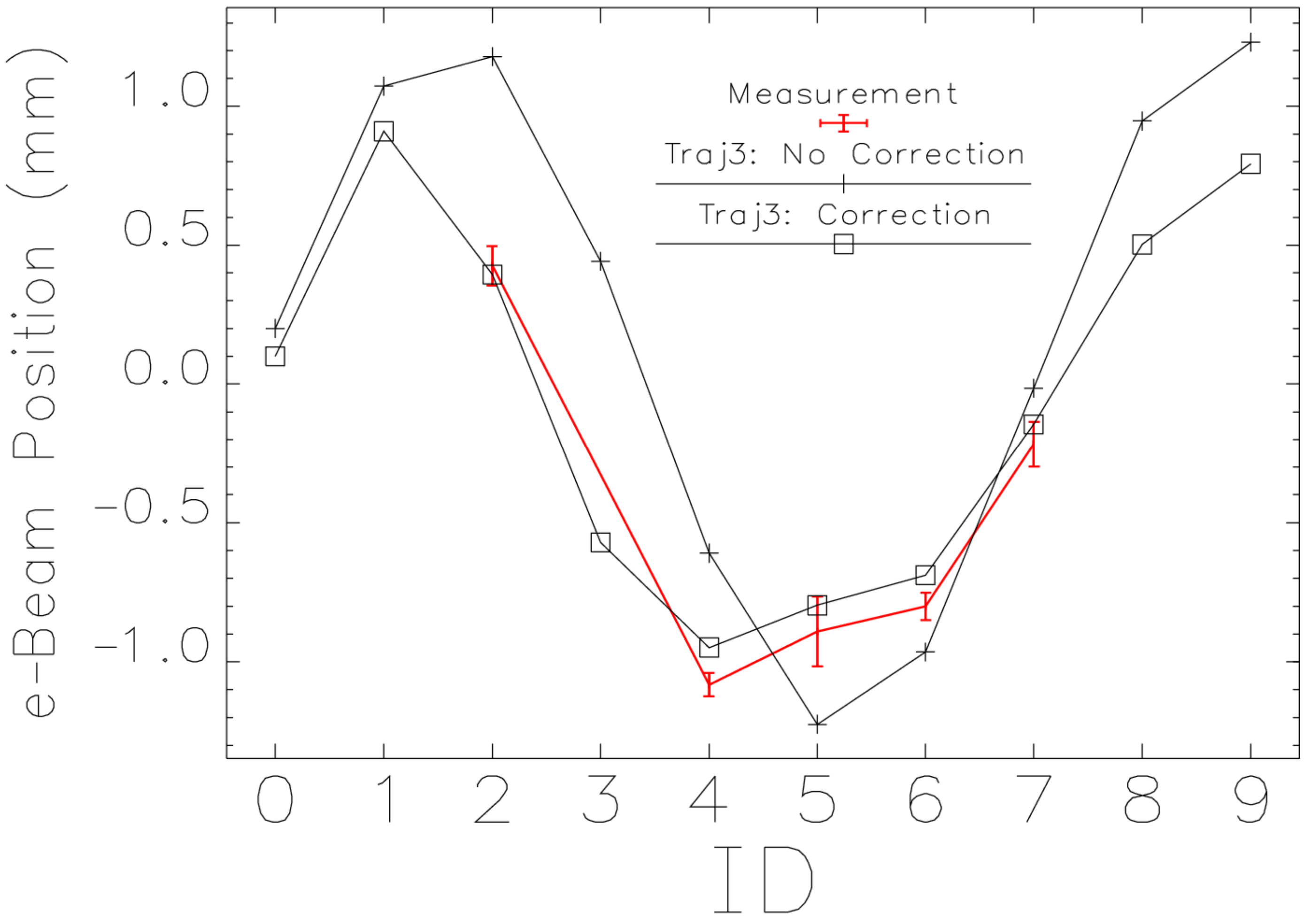
Simulation Result: SASE



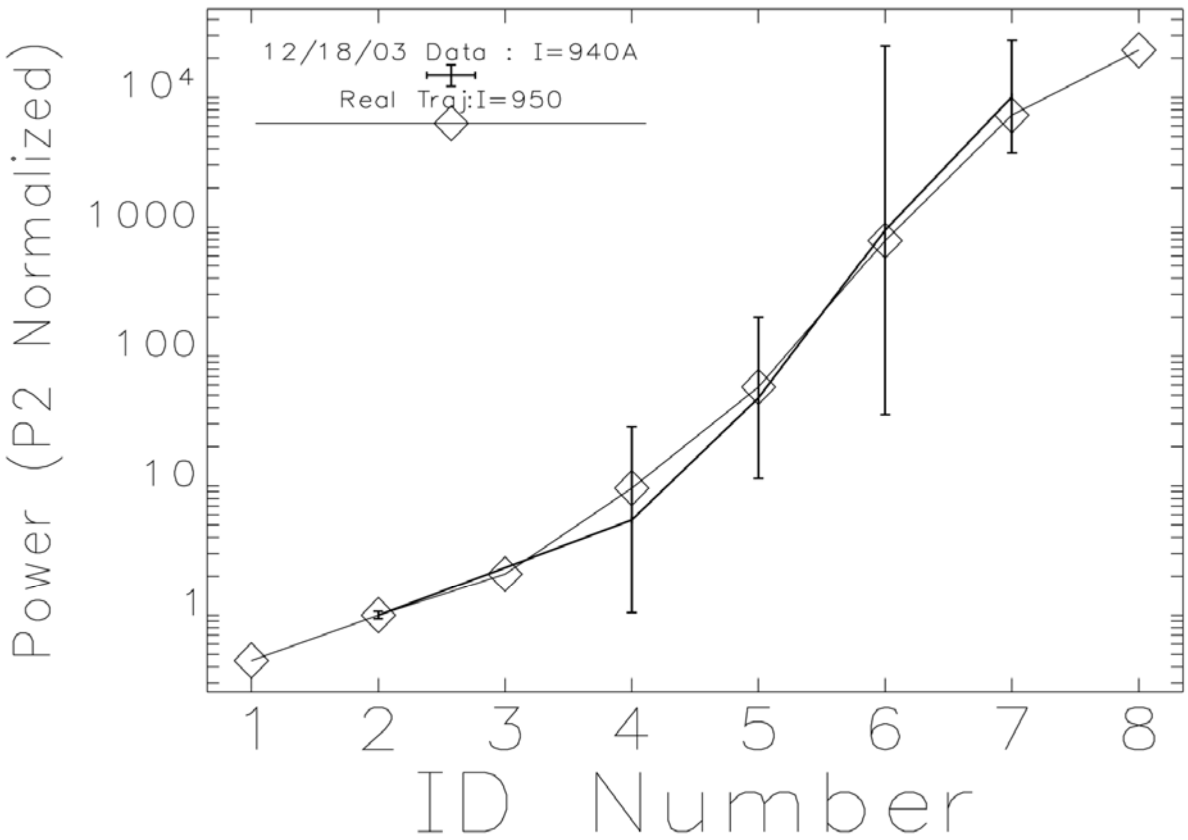
SKE Experiment

- **We found that Tanaka's model on SKE fitted the experimental data well.**
- **Also good agreements between theory and the simulation.**

Find Trajectory: $\langle\beta\rangle$ = 3 m



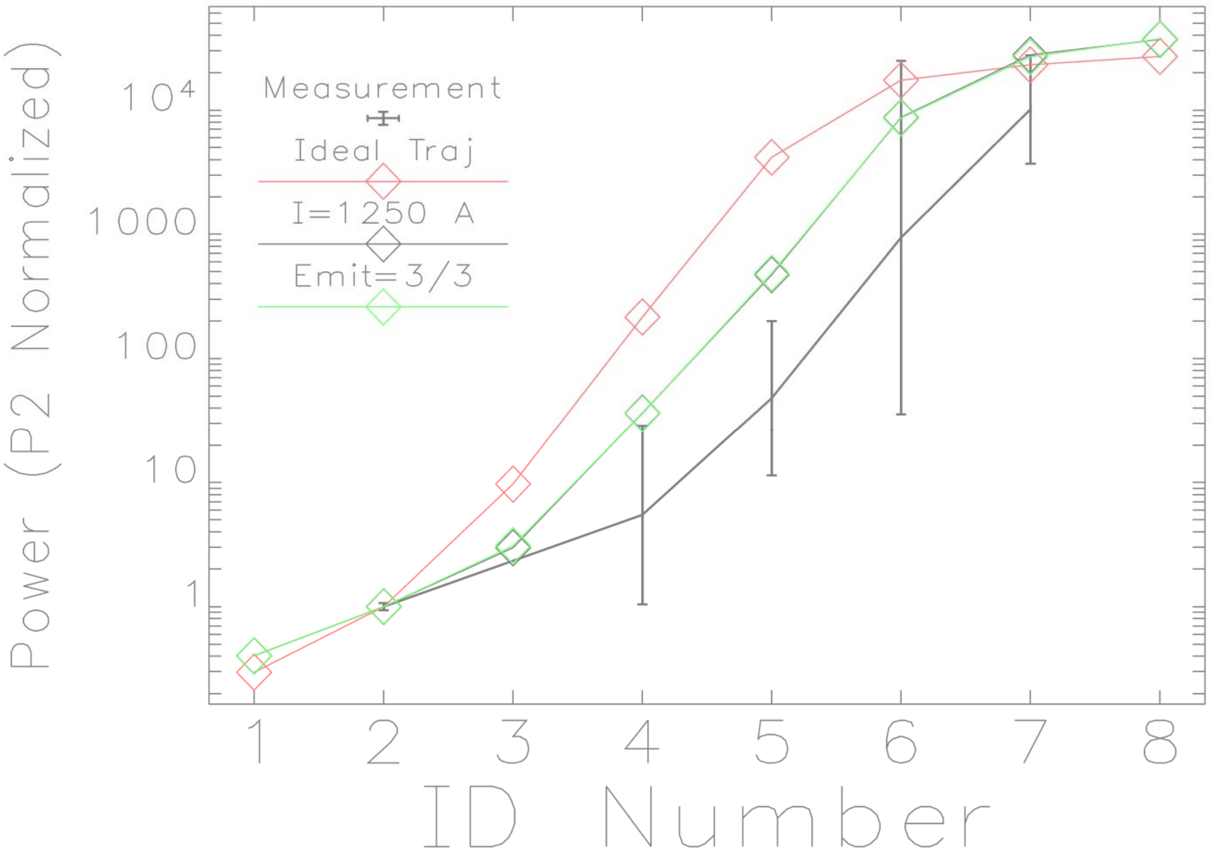
Trajectory Confirmed



Measured Beam:
Q = 250 pC
FWHM = 250 fs
Ipeak = 940 A
EMIT = 4.5/3.5 π
ΔE/E = 0.15%

Simulated Beam:
Ipeak = 950 A

Performance Upgrade:Trajectory



<u>Real Trajectory</u>

Ip=950 ➔ 1250 A

or

ε=4.5/3.5 ➔ 3.0/3.0 μm

VS.

<u>Ideal Trajectory</u>

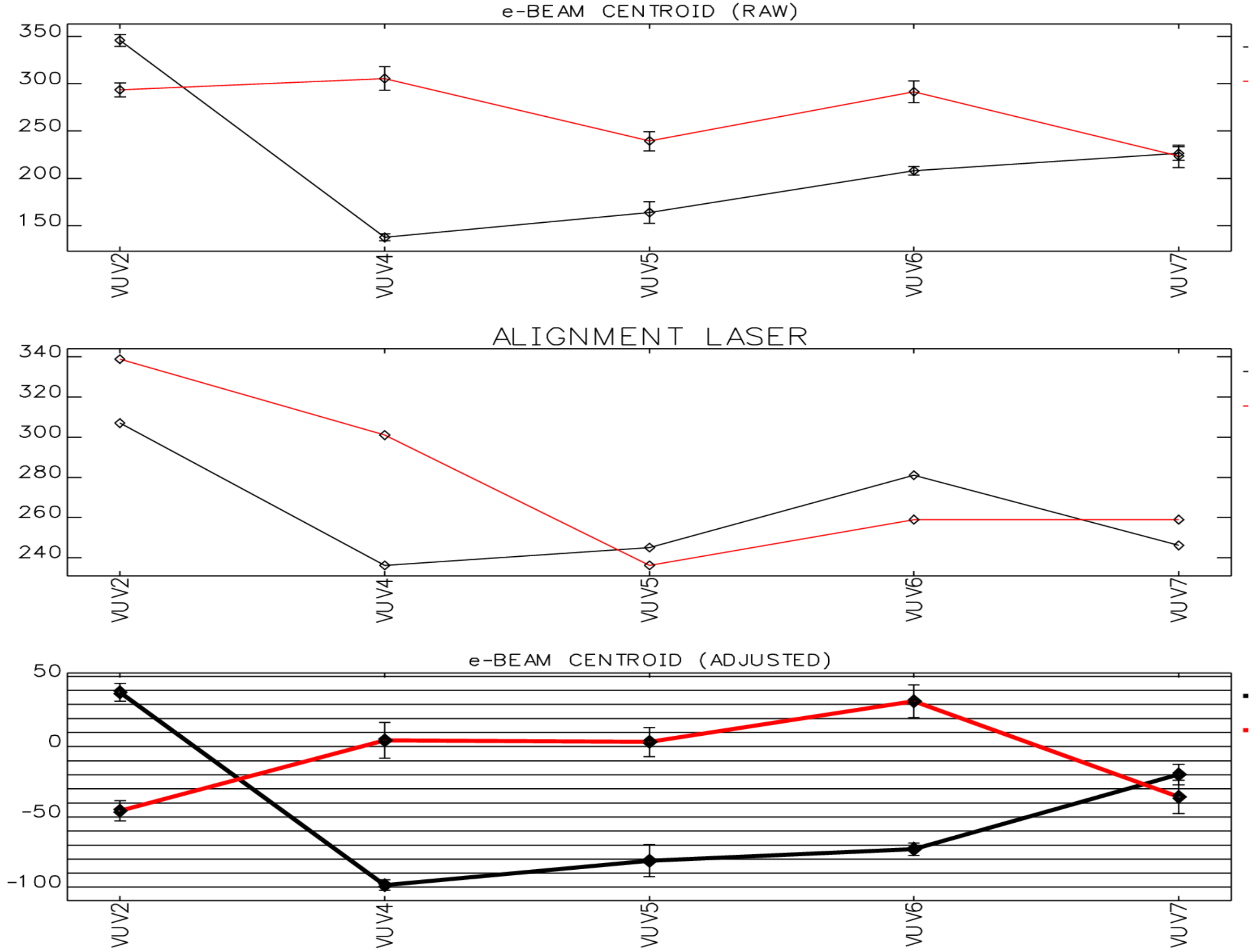
Summary

- **Single-Kick-Error Effects: Theory, Experiment, Simulation showing good agreements.**
  - We just completed the 2nd experiment (8/21/04).
- **The beam parameters on 12/18/03 was as good as we could get; the performance upgrade could be achieved by further orbit optimization.**
  - We had requested upgrading BPM systems.
- **SKE effects are more serious in short wavelength FEL.**

End of Slides

(Back up slides follows)

A LEUTL Trajectory (12/18/03)

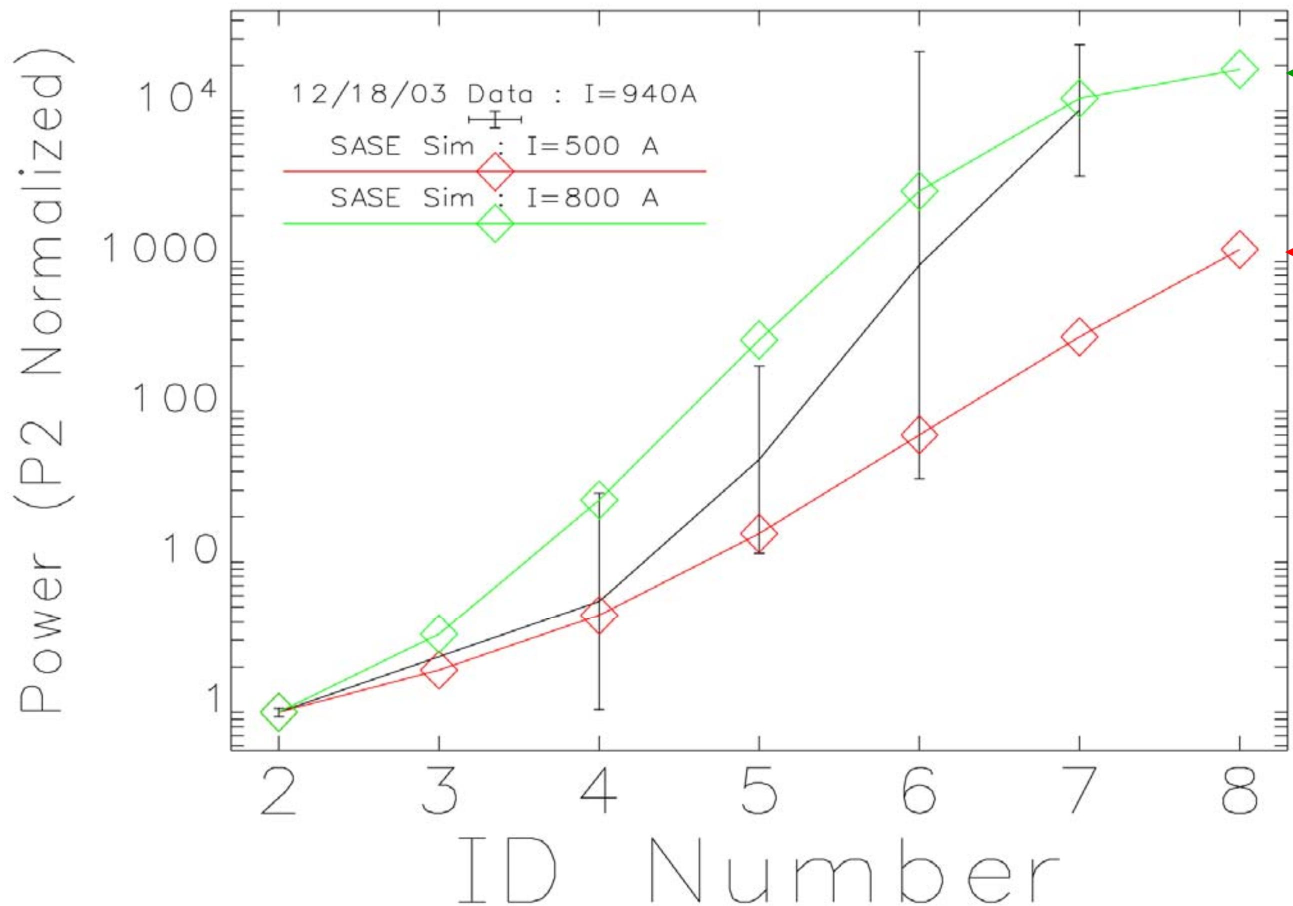


e-beam

Alignment Laser

Trajectory

LEUTL Trajectory Effect



Ideal Orbit

I=800 A

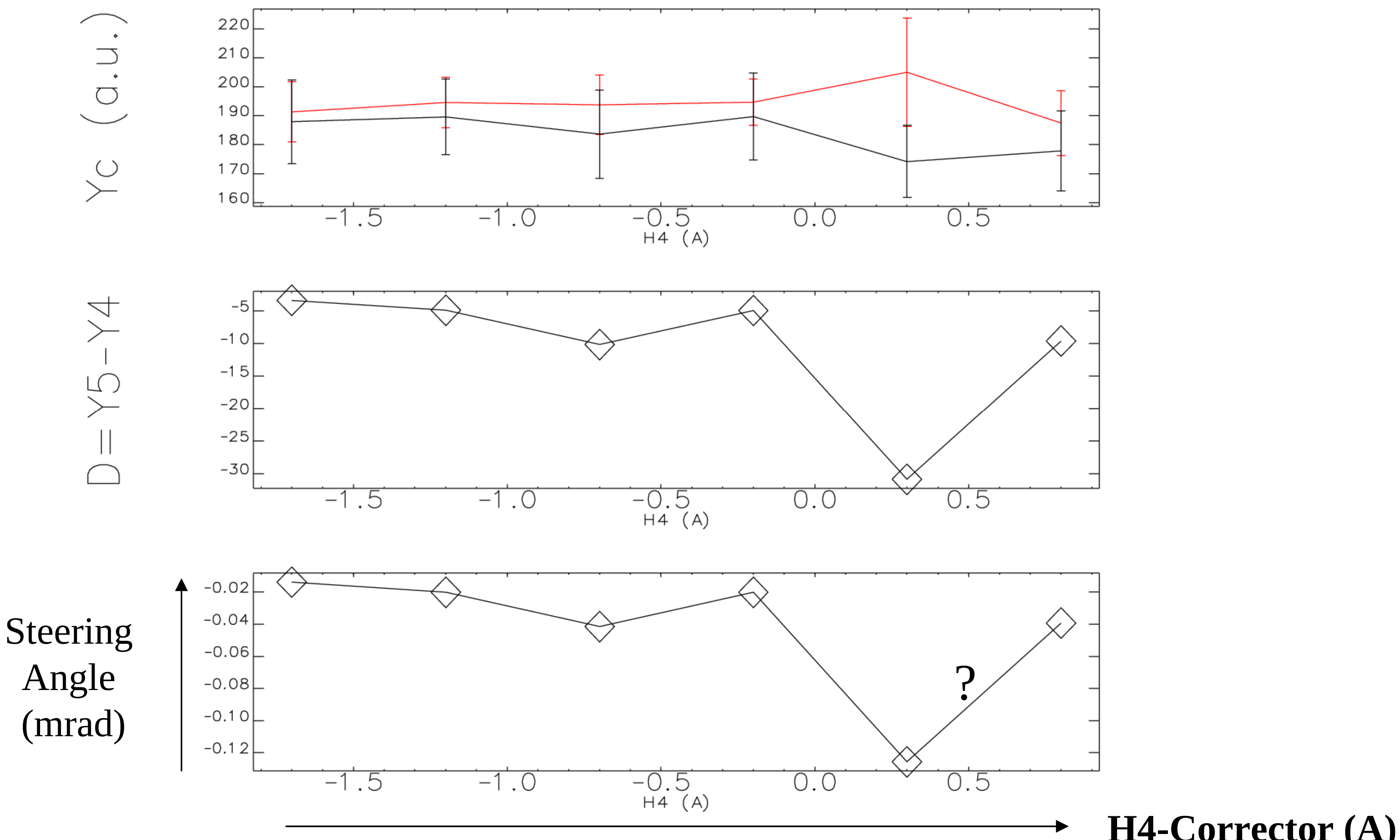
I=500A

Vs

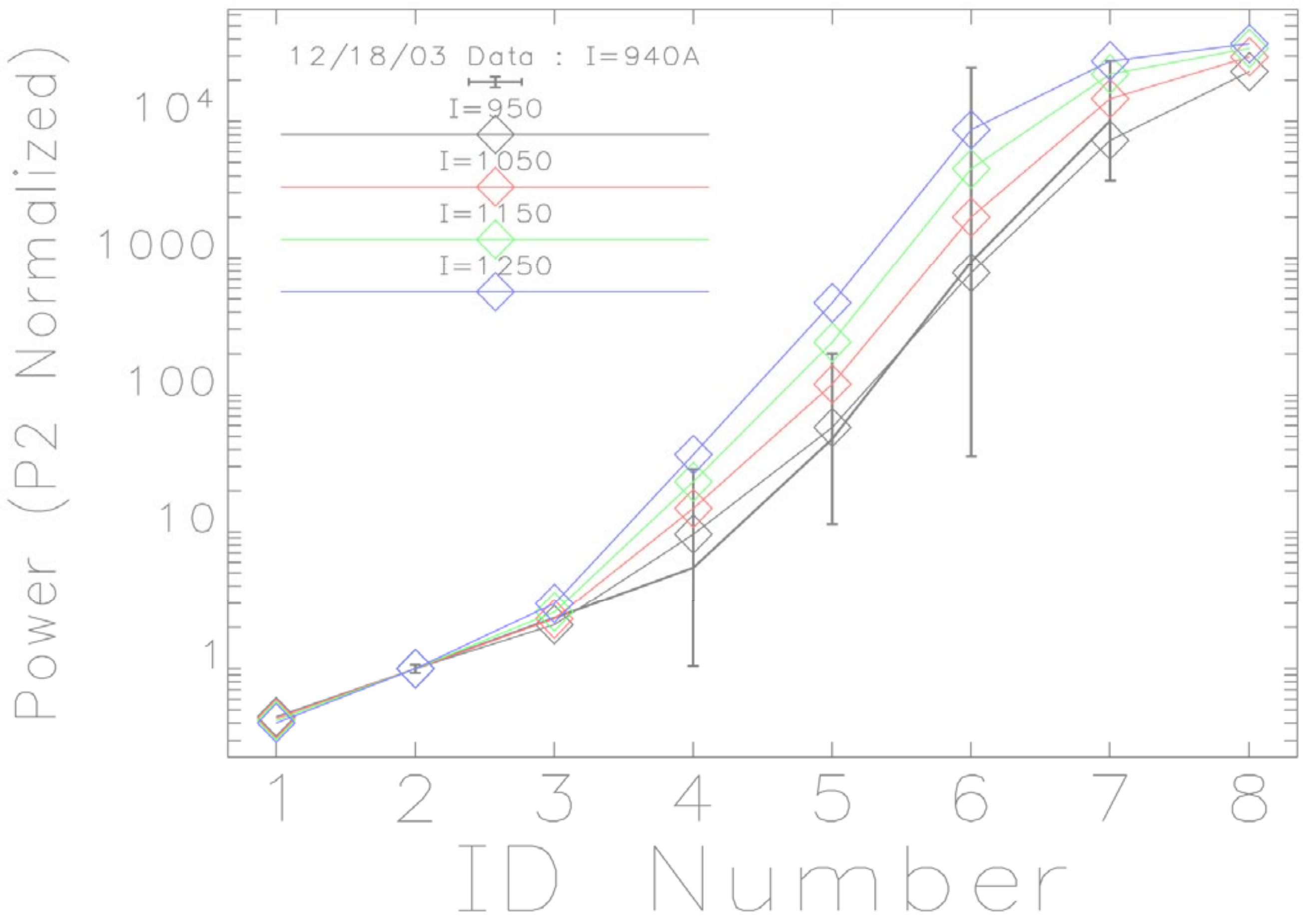
Real Orbit

I=940 A

SKE Experiment: e-Beam (y-position)



Performance Upgrade: Ipeak (950 A → 1250 A)



Performance Upgrade: Emittance (5 $\mu m \rightarrow 3\ \mu m$)