# Preliminary Measurements of Trajectory Effect at LEUTL

By

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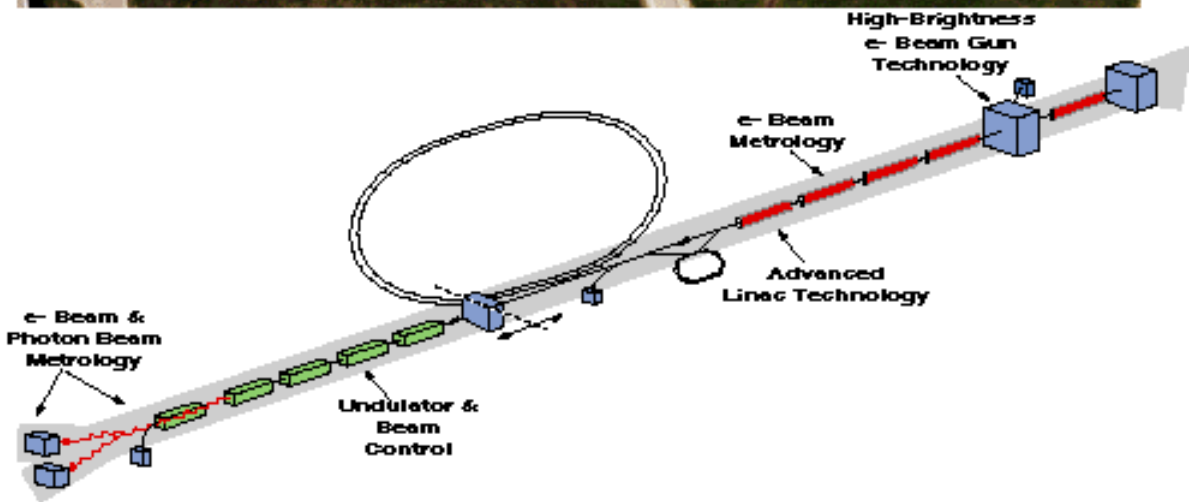
# Motivation

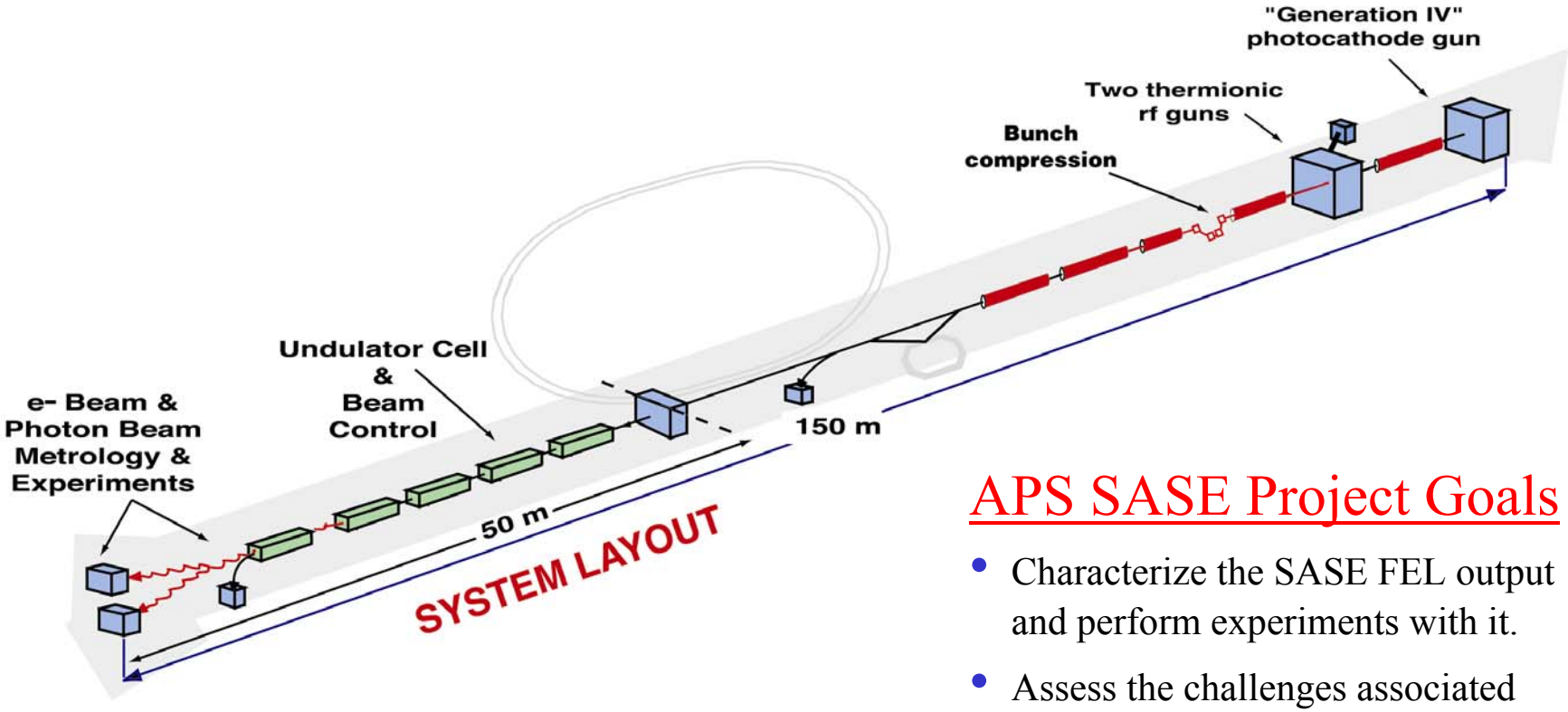
- T. Tanaka's et al, "Consideration on an Alignment Tolerance of BPMs for SCSS Undulator Line," FEL 2003 Workshop
- Tanaka claimed that trajectory error can be more serious in degrading FEL performance than undulator field errors (I will show some of his transparencies).
- Verify Tanaka's formula by measurement and simulation at APS's LEUTL facility which may help to understand the orbit effects quantitatively.

# LEUTL


High-Brightness
e- Beam Gun
Technology
e- Beam
Metrology
Advanced
Linac Technology
e- Beam &
Photon Beam
Metrology
Undulator &
Beam
Control

# The APS SASE FEL Schematic

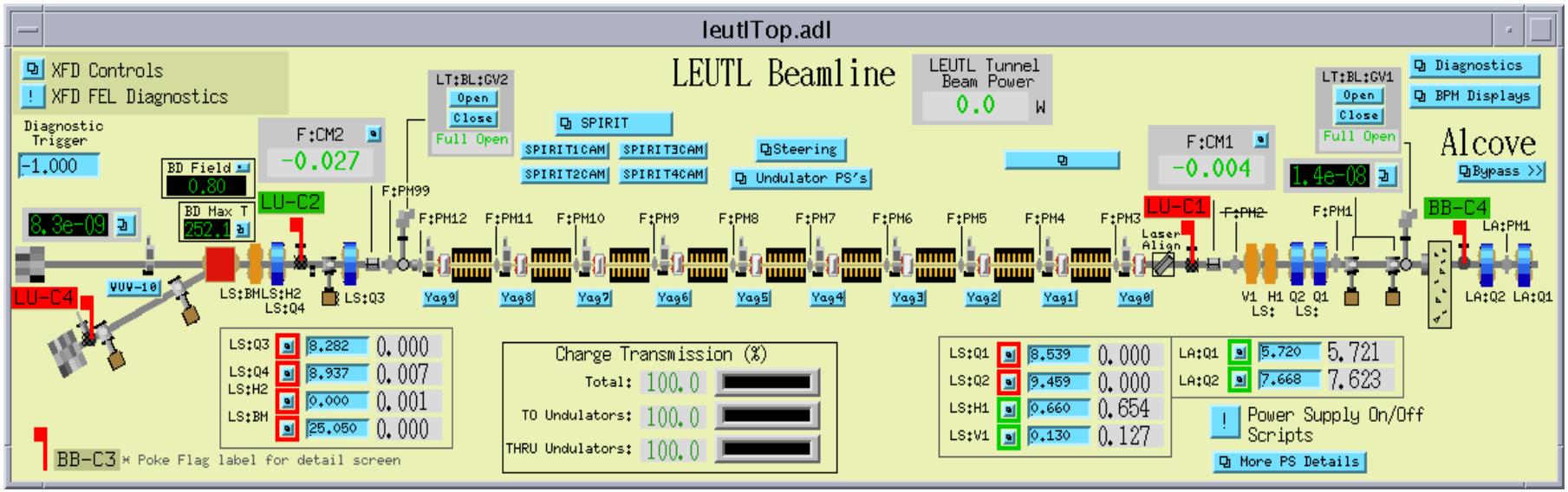
## The Low-Energy Undulator Test Line System
## Present Configuration

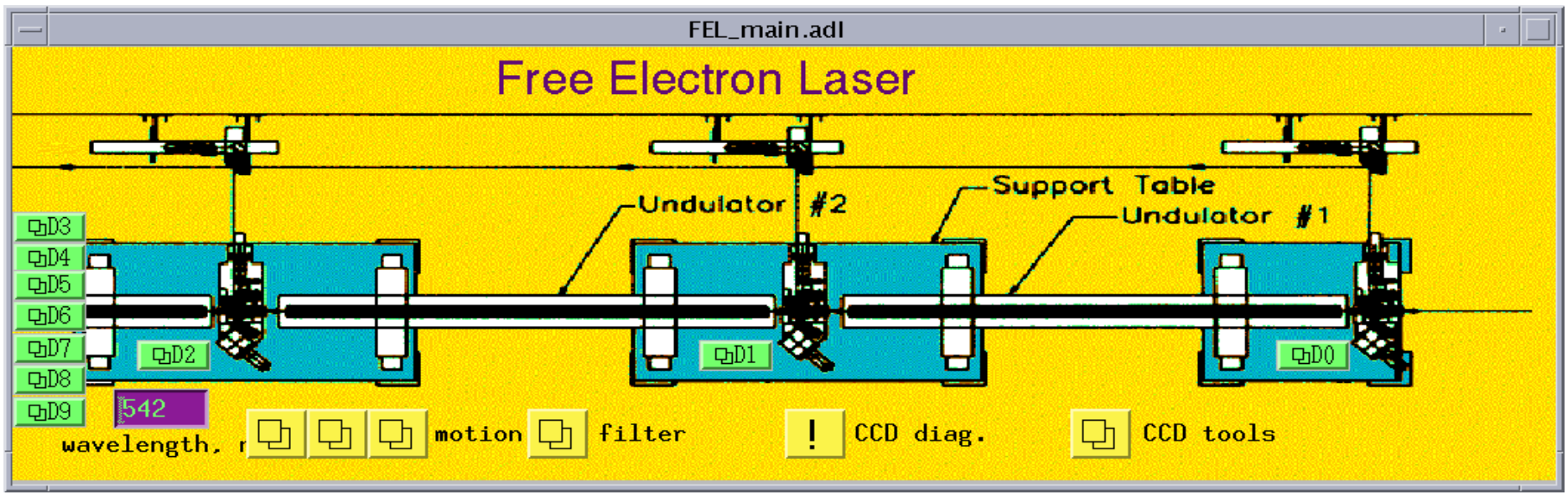



## APS SASE Project Goals

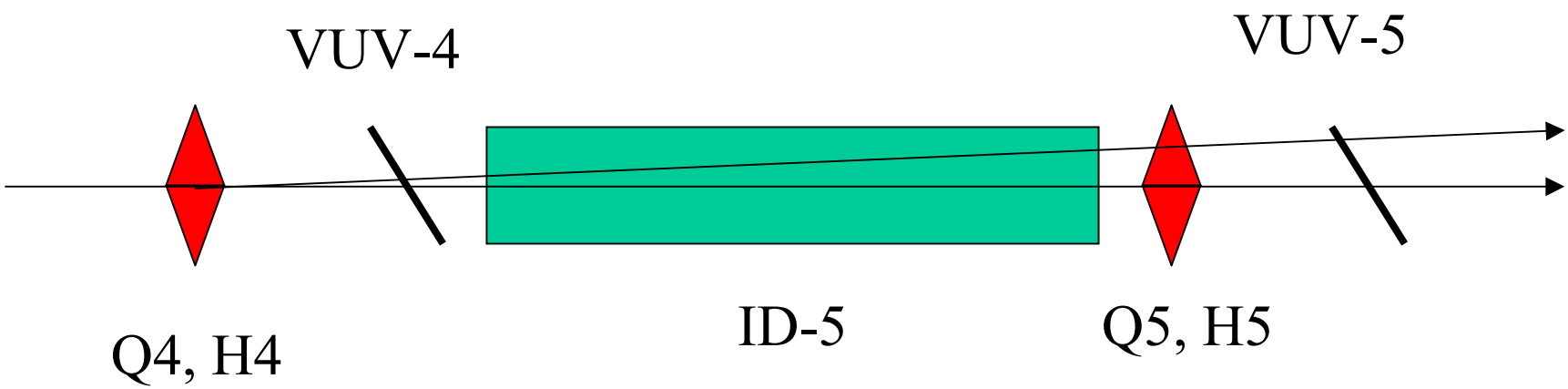
- Characterize the SASE FEL output and perform experiments with it.
- Assess the challenges associated with producing a SASE FEL in preparation for an x-ray regime machine.

# LEUTL


leutlTop.adl
XFD Controls
XFD FEL Diagnostics
LEUTL Beamline
LEUTL Tunnel Beam Power
0.0
W
Diagnostics
BPM Displays
Alcove
Bypass >>
Diagnostic Trigger
-1.000
BD Field
0.80
BD Max T
252.1
F:CM2
-0.027
F:CM1
-0.004
LT:BL:GV2
LT:BL:GV1
Open
Close
Full Open
SPIRIT
SPIRIT1CAM
SPIRIT2CAM
SPIRIT3CAM
SPIRIT4CAM
Steering
Undulator PS's
8.3e-09
1.4e-08
LU-C2
LU-C1
LU-C4
BB-C4
F:PM99
F:PM12
F:PM11
F:PM10
F:PM9
F:PM8
F:PM7
F:PM6
F:PM5
F:PM4
F:PM3
F:PM2
F:PM1
Laser Align
VUV-10
LS:BM
LS:H2
LS:Q4
LS:Q3
Yag9
Yag8
Yag7
Yag6
Yag5
Yag4
Yag3
Yag2
Yag1
Yag0
V1 H1 Q2 Q1
LS:
LA:PM1
LA:Q2 LA:Q1
LS:Q3 8.282 0.000
LS:Q4 8.937 0.007
LS:H2 0.000 0.001
LS:BM 25.050 0.000
Charge Transmission (%)
Total: 100.0
TO Undulators: 100.0
THRU Undulators: 100.0
LS:Q1 8.539 0.000
LS:Q2 9.459 0.000
LS:H1 0.660 0.654
LS:V1 0.130 0.127
LA:Q1 5.720 5.721
LA:Q2 7.668 7.623
Power Supply On/Off Scripts
More PS Details
BB-C3
* Poke Flag label for detail screen

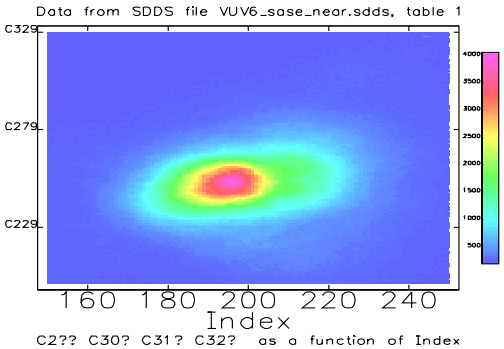

FEL_main.adl
Free Electron Laser
Undulator #2
Support Table
Undulator #1
D3
D4
D5
D6
D7
D8
D9
D2
D1
D0
542
wavelength, r
motion
filter
CCD diag.
CCD tools

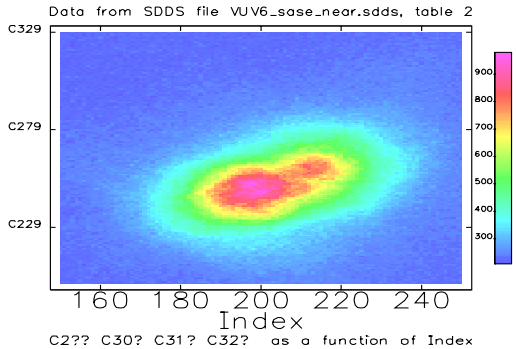
# Single-Kick-Error (SKE) Experiment: Configuration

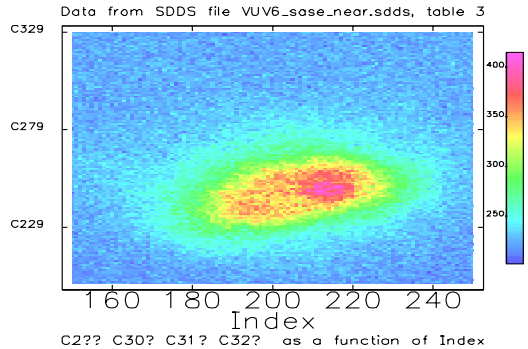


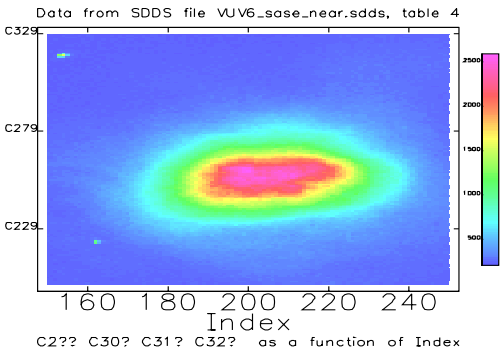

1. Turn Off Q5, H5
2. Vary H4
3. Observe CTR at VUV-4 and VUV-5 ➔ Angle = (X5-X4)/L
4. Observe UR at VUV-4 and VUV-5 ➔ Gain = P5/P4

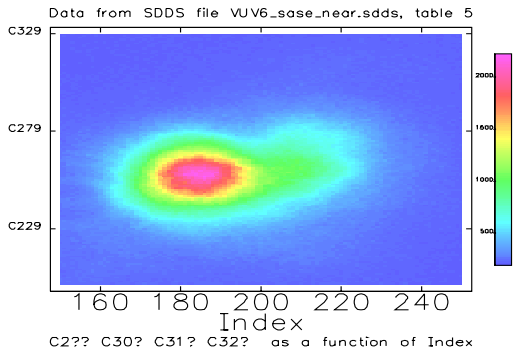
# Undulator Radiation (UR)

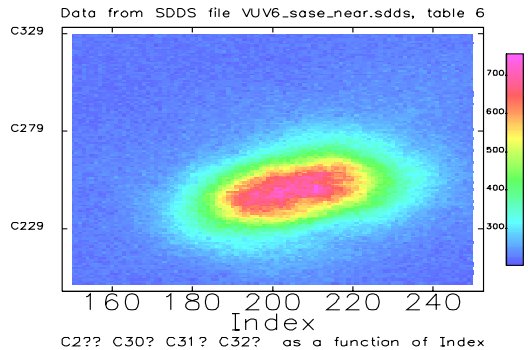


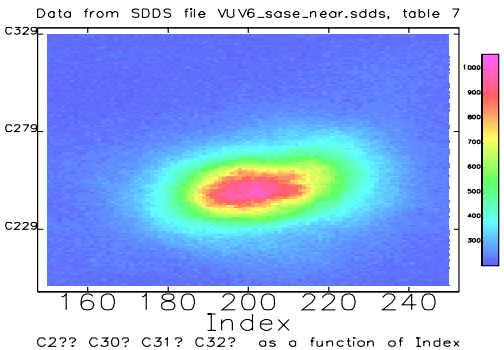



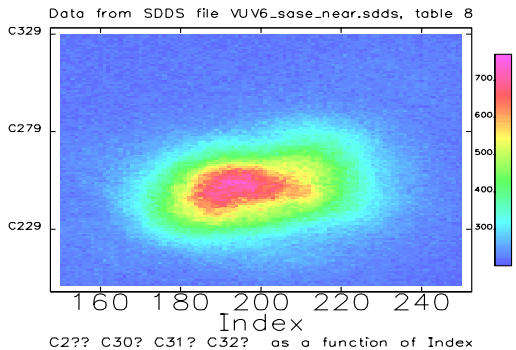



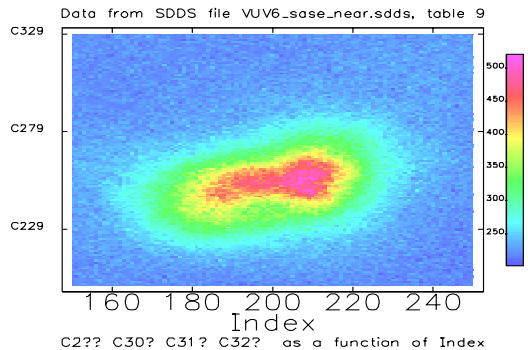



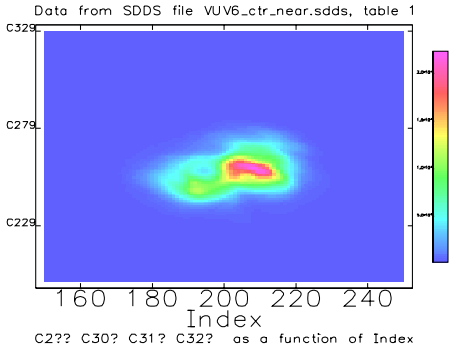



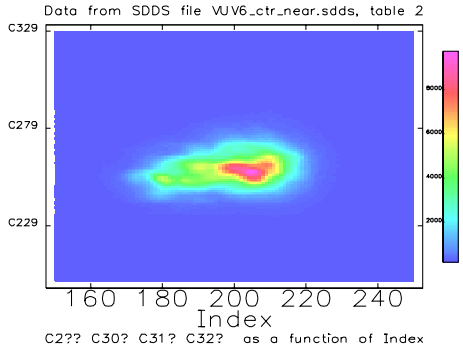



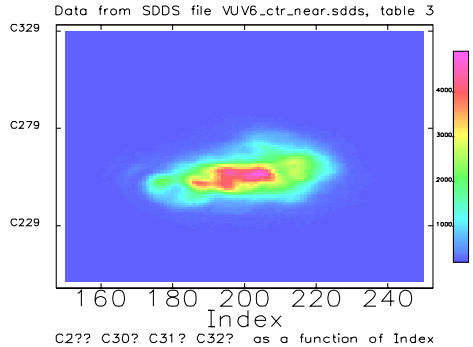



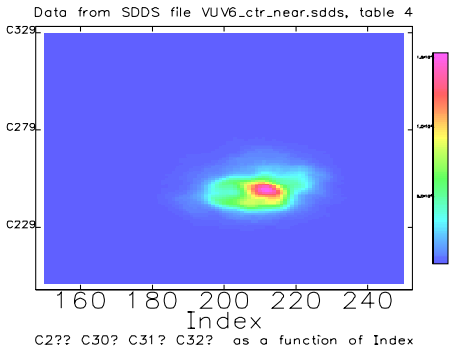



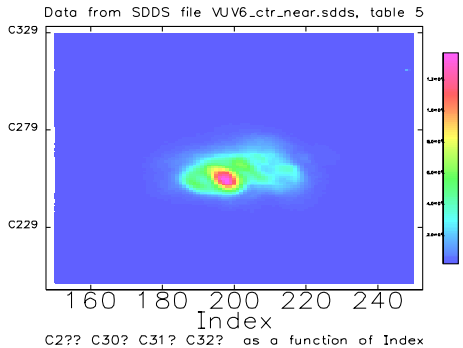
# Coherent Transition Radiation (CTR)

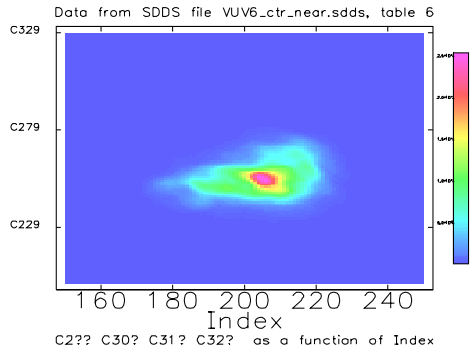


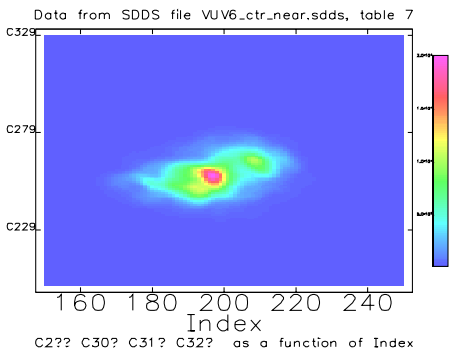



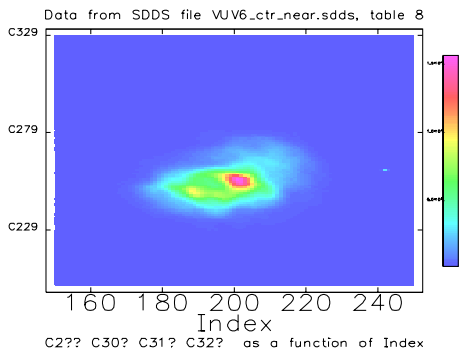



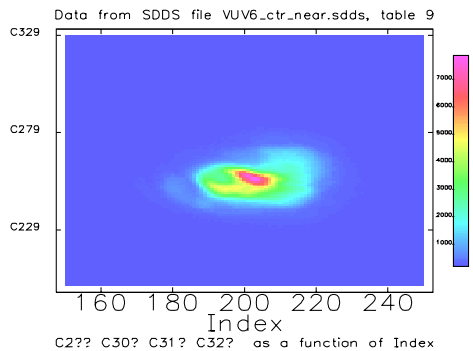



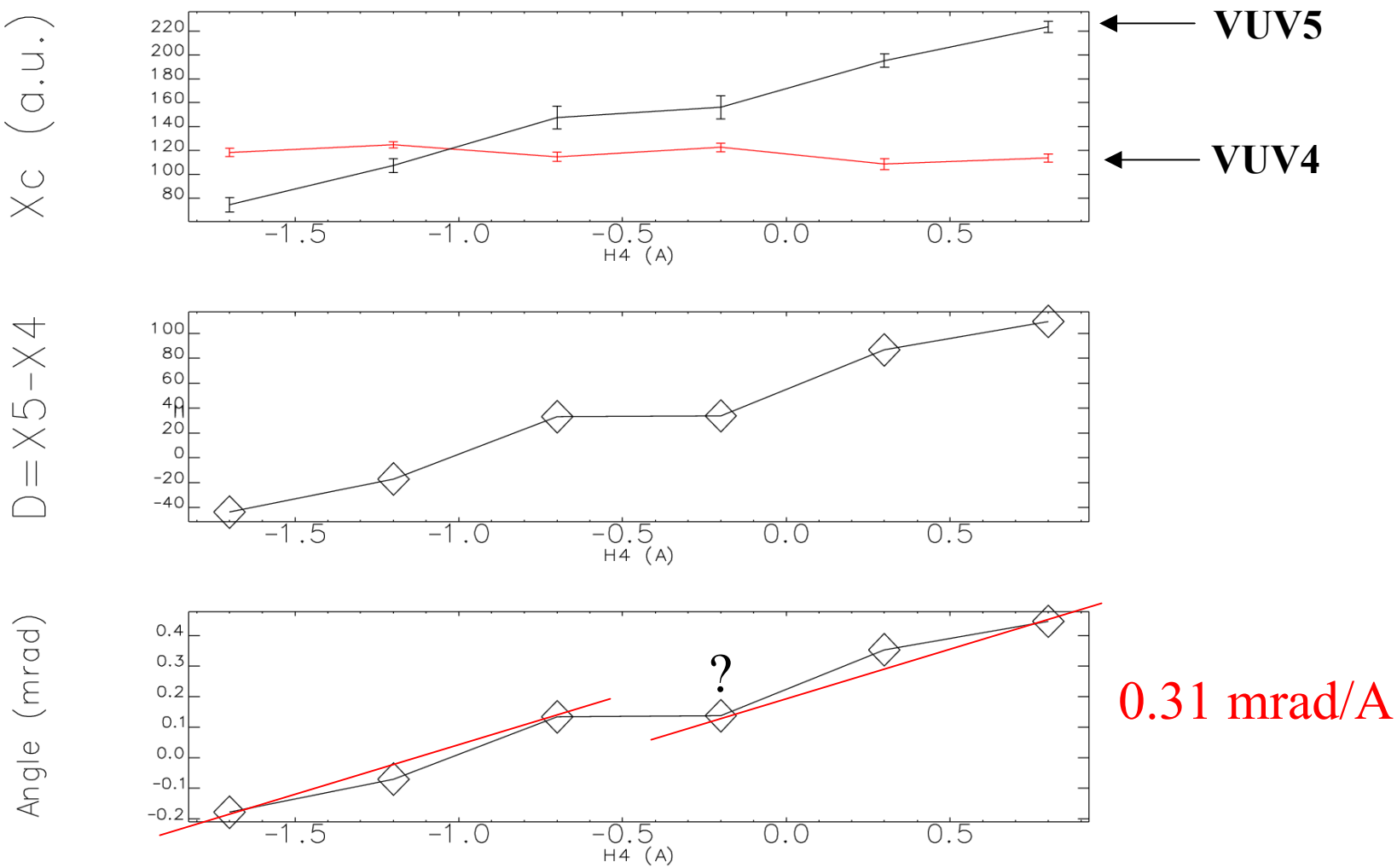



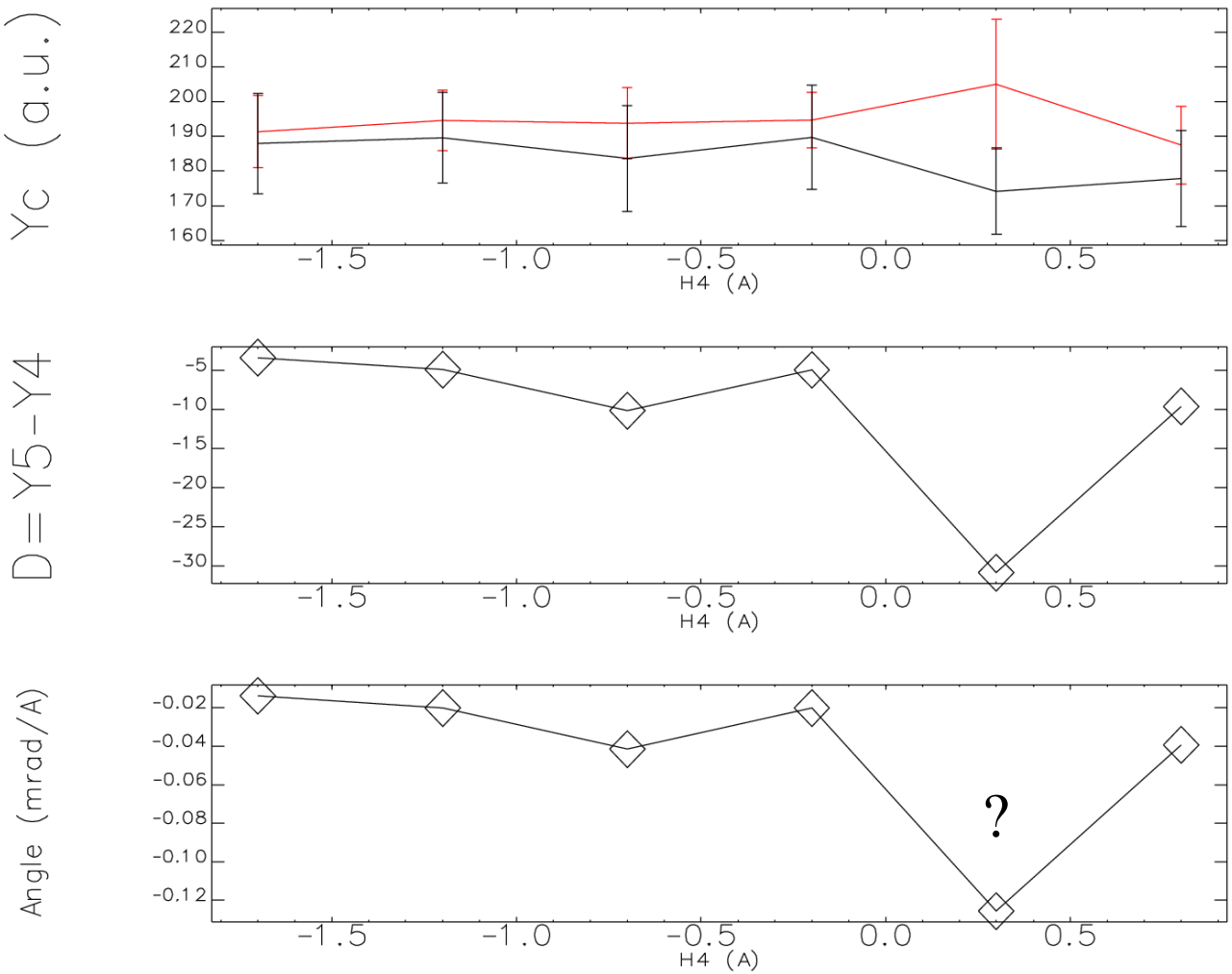
# SKE Experiment: e-Beam (1)




0.31 mrad/A

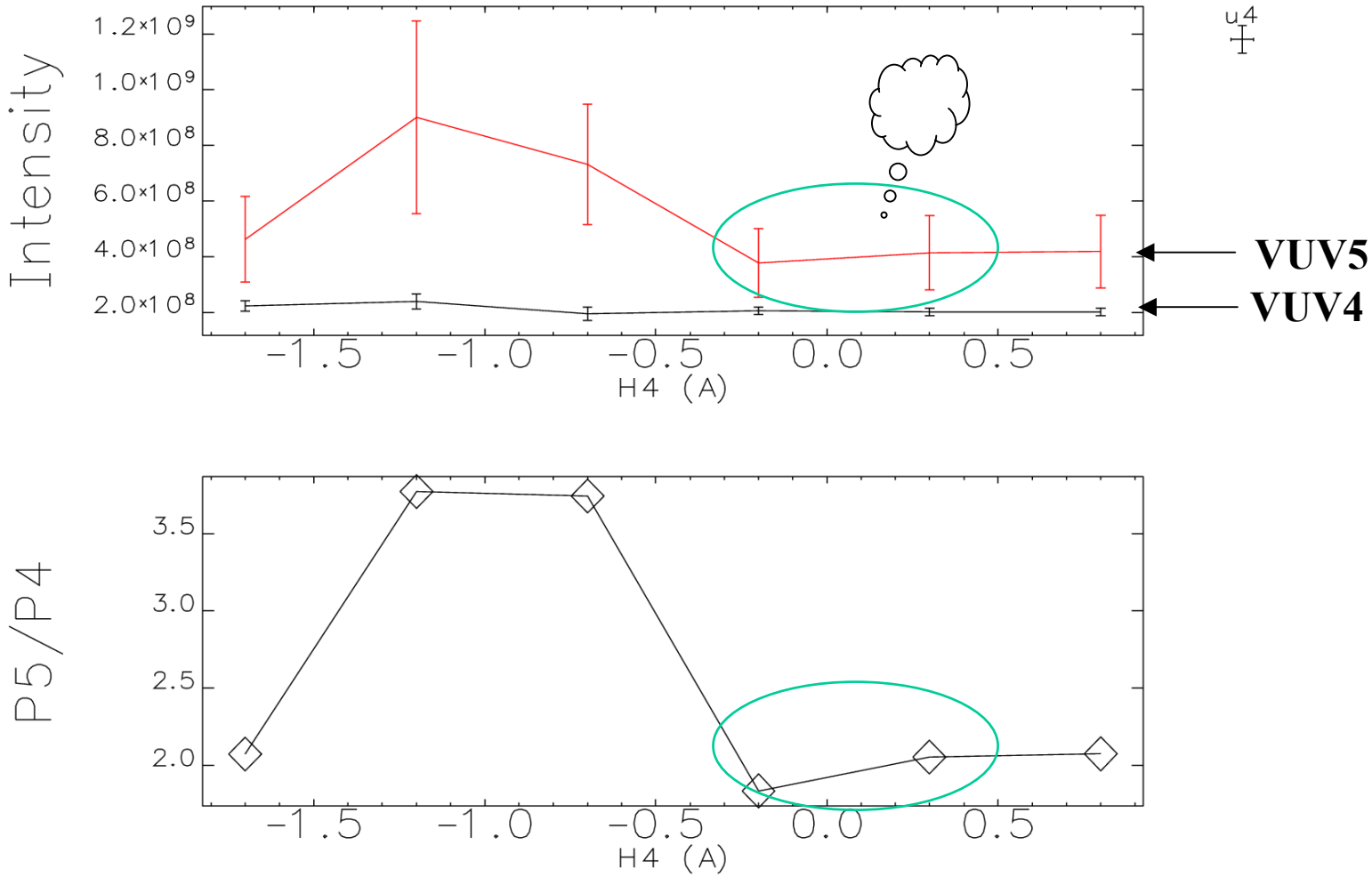
CTR near field 12/18/03

# SKE Experiment: e-Beam (2)




CTR near field 12/18/03

# SKE Experiment: Intensity




SASE far field 12/18/03

# Fit Formula

## 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

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

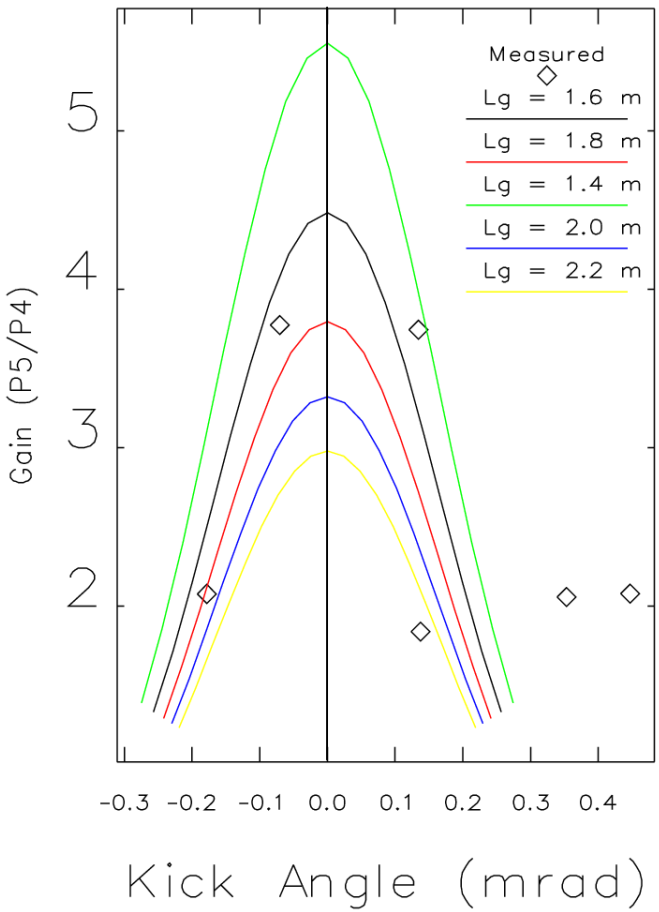
$x=\theta/\theta_c$ ; $\theta$=*kick angle,*
*Offset* $x_0$ *to be determined*

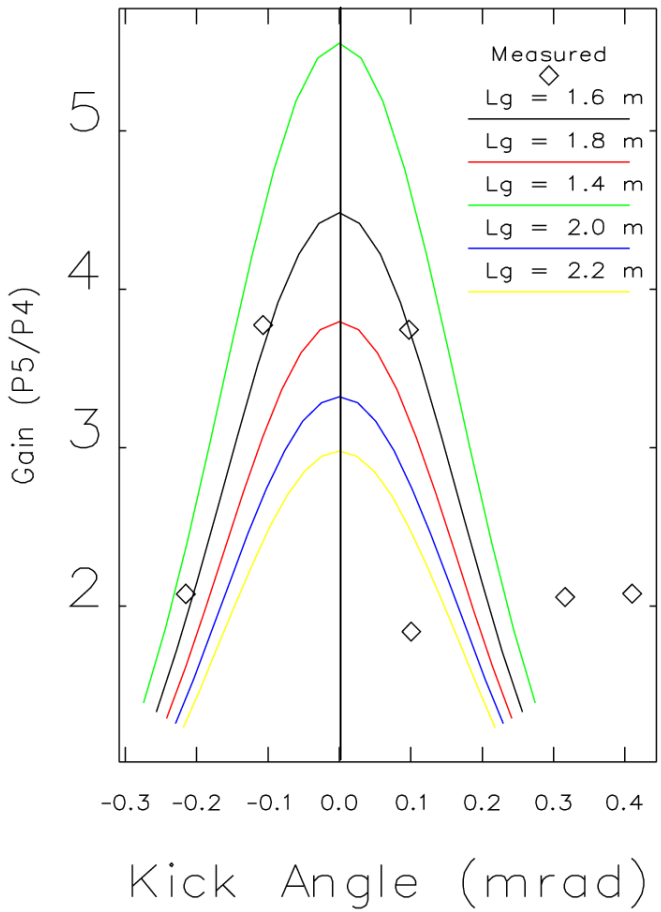
## 3. Fit Parameter: $L_g$, $x_0$

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

# Experiment vs. Theory

**$L_g$ (Ideal Orbit) = 1.6 m !**




Angle Corrected by the Offset 0.037 mrad

SASE far field 12/18/03

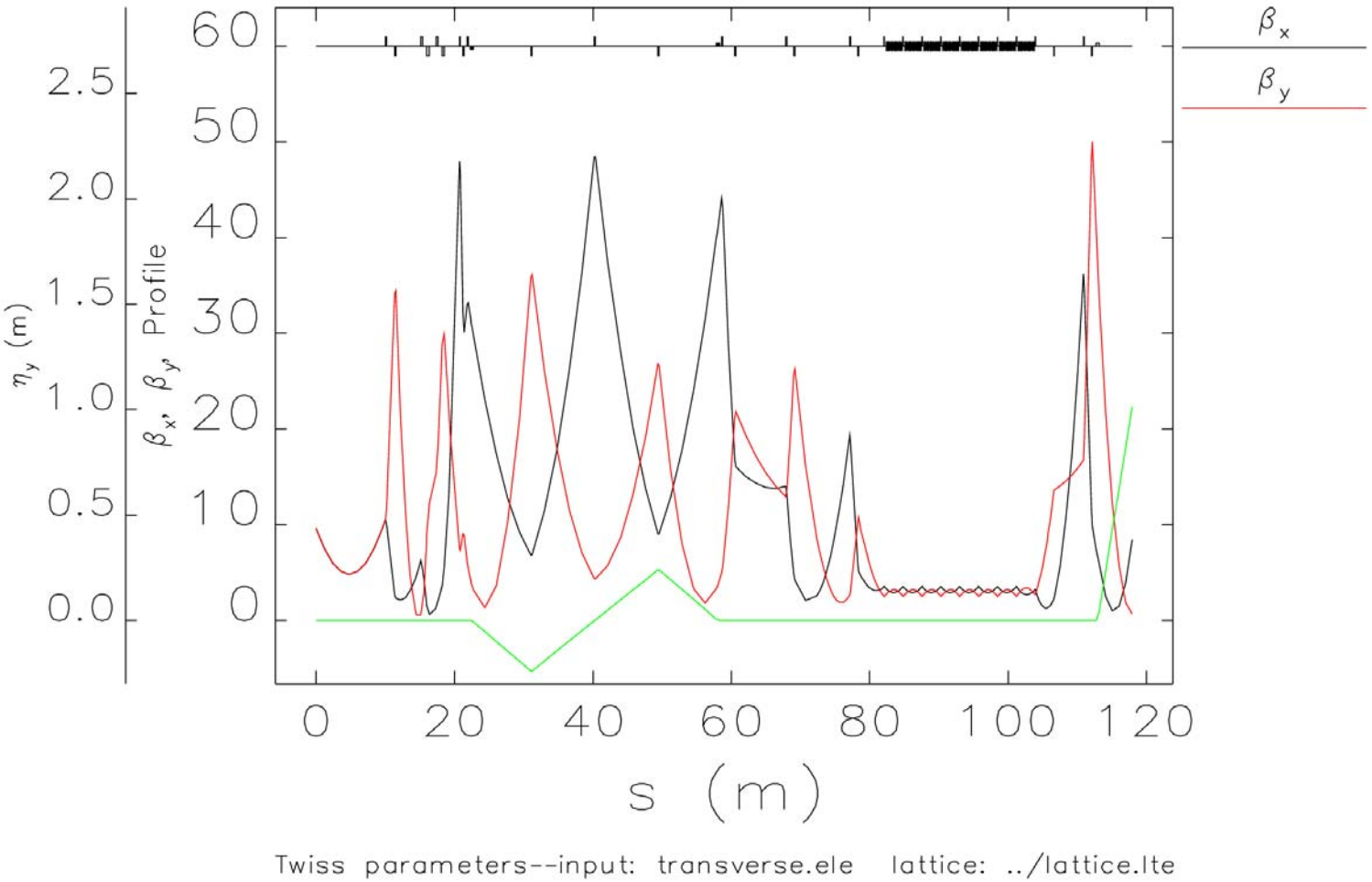
# Next Step: Simulation

- Simulation Program: GENESIS 1.3

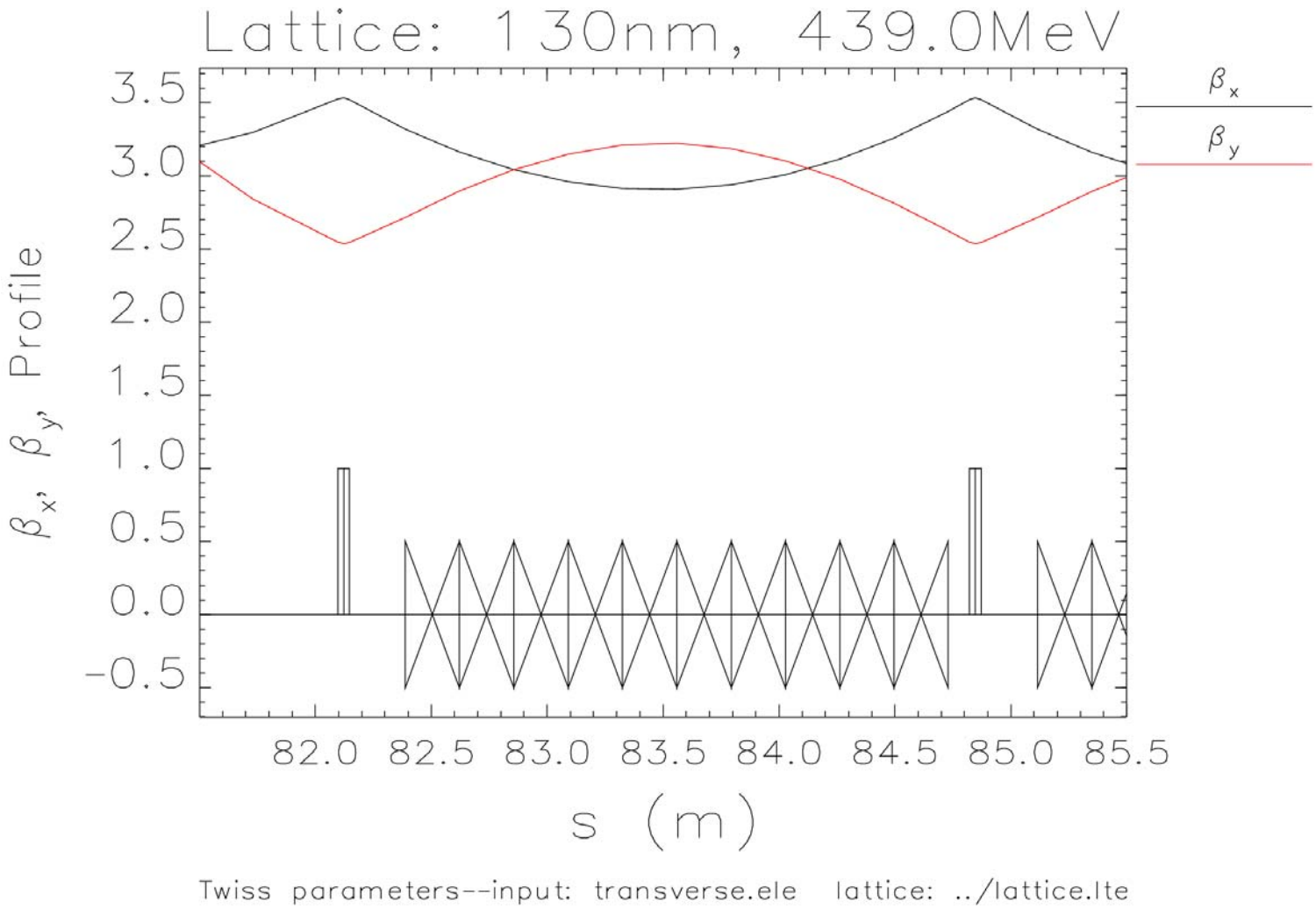
- Nominal simulation parameter
  - $\lambda s$=130 nm,
  - E=439 MeV, $\Delta E/E$=0.15 %
  - Ip=600 A, FWHM=200 fs
  - Emittance=5 $\pi$ mm-mrad

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

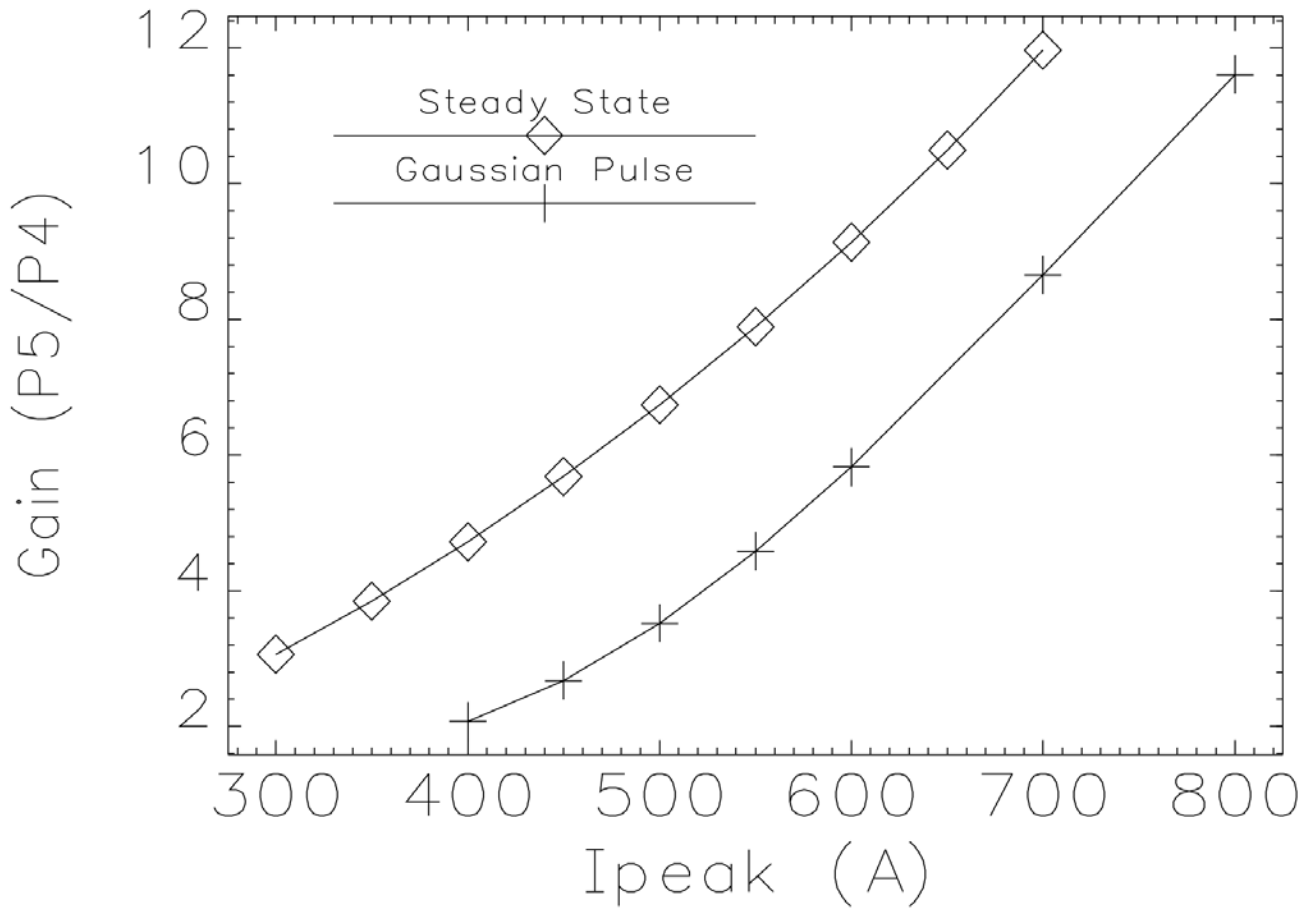
# Simulation: Lattice Setup (1)



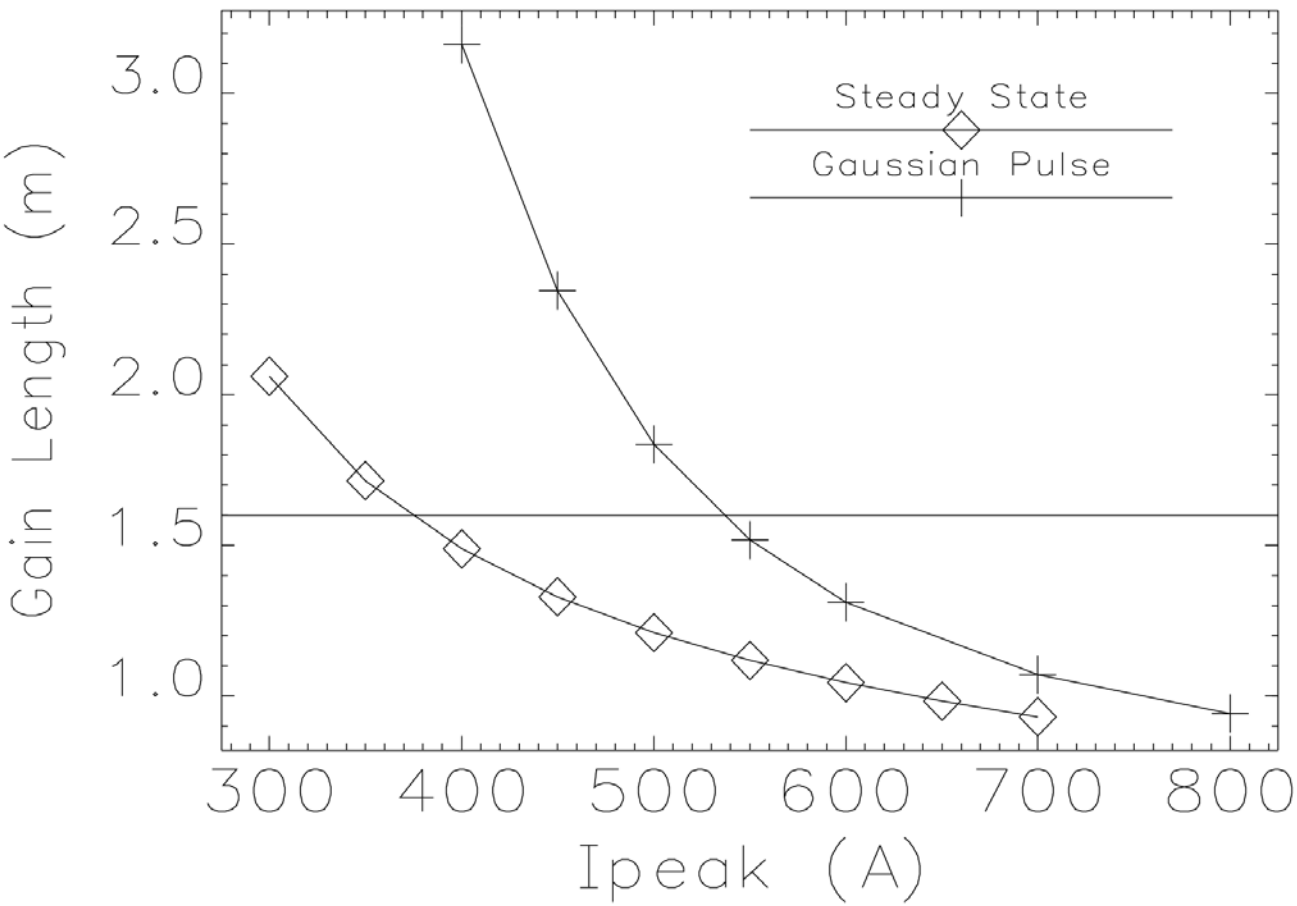
# Simulation: Lattice Setup (2)



# Simulation: Gain vs. Ipeak



# Simulation: Lgain vs. Ipeak

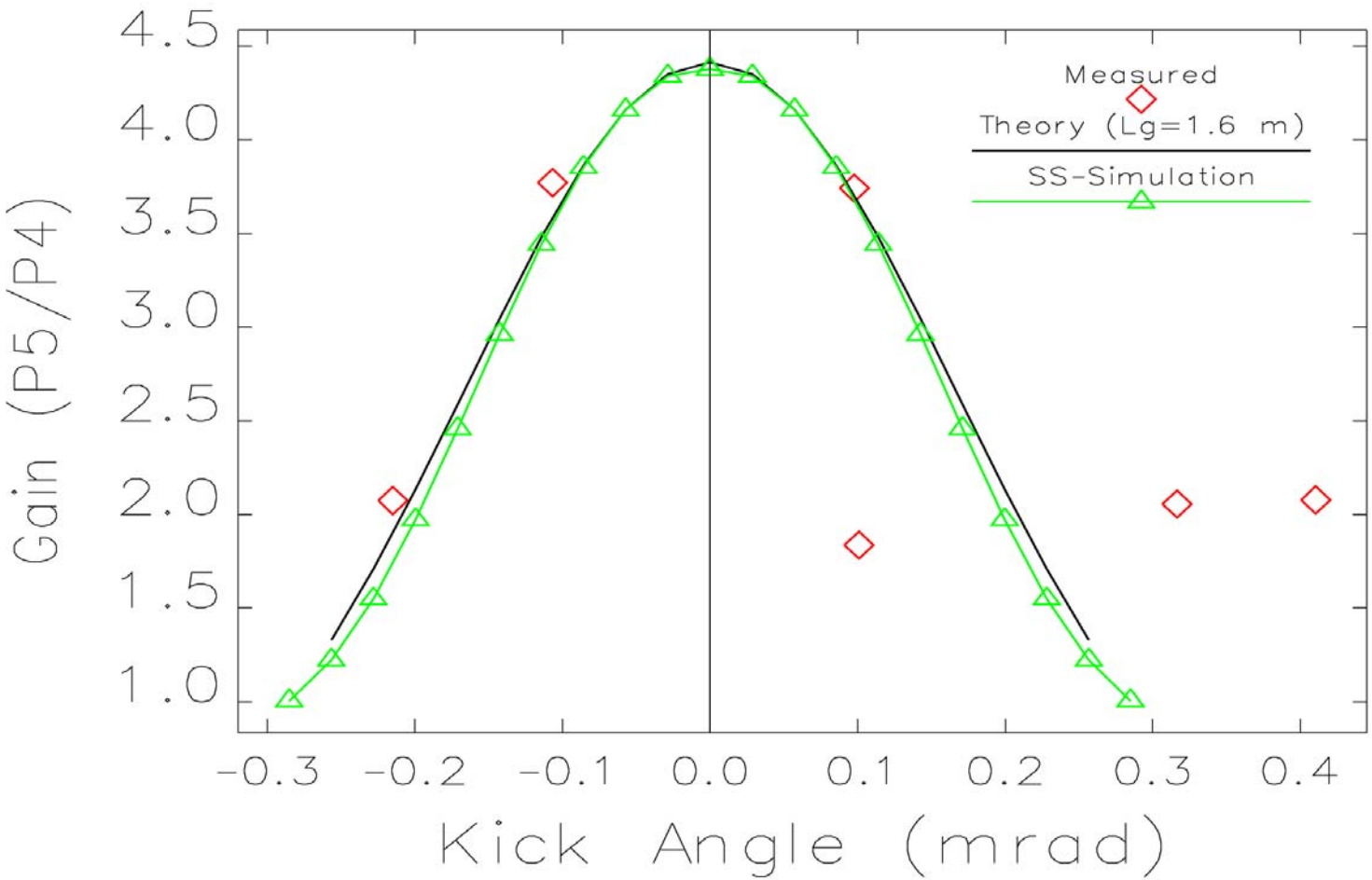



**Simulation parameter representing 12/18/03 experimental condition is now found!**

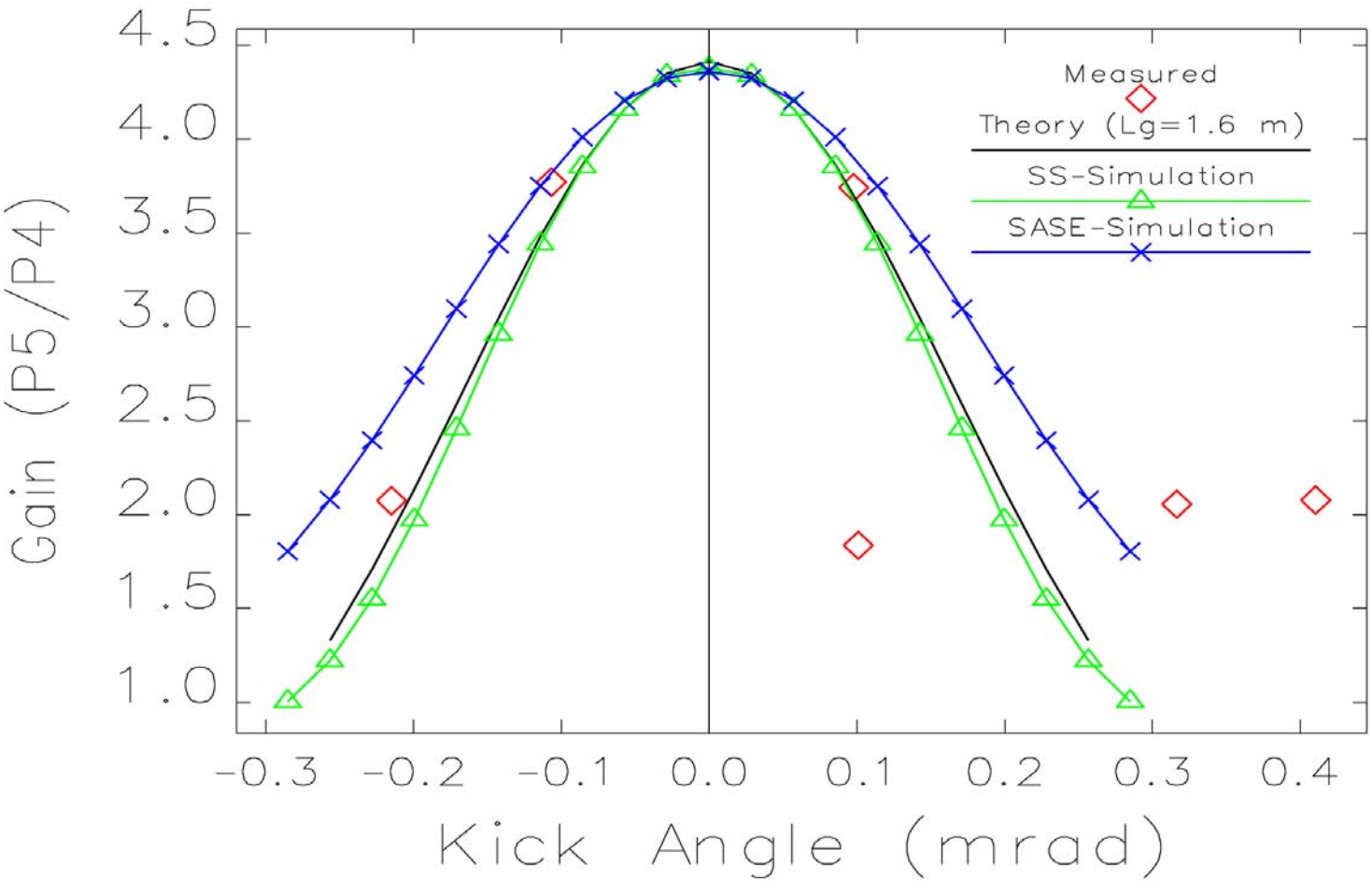
**Ip = 380 A**
for Steady State

**Ip= 540 A**
for 200 fs FWHM pulse

# Simulation: Results (1)



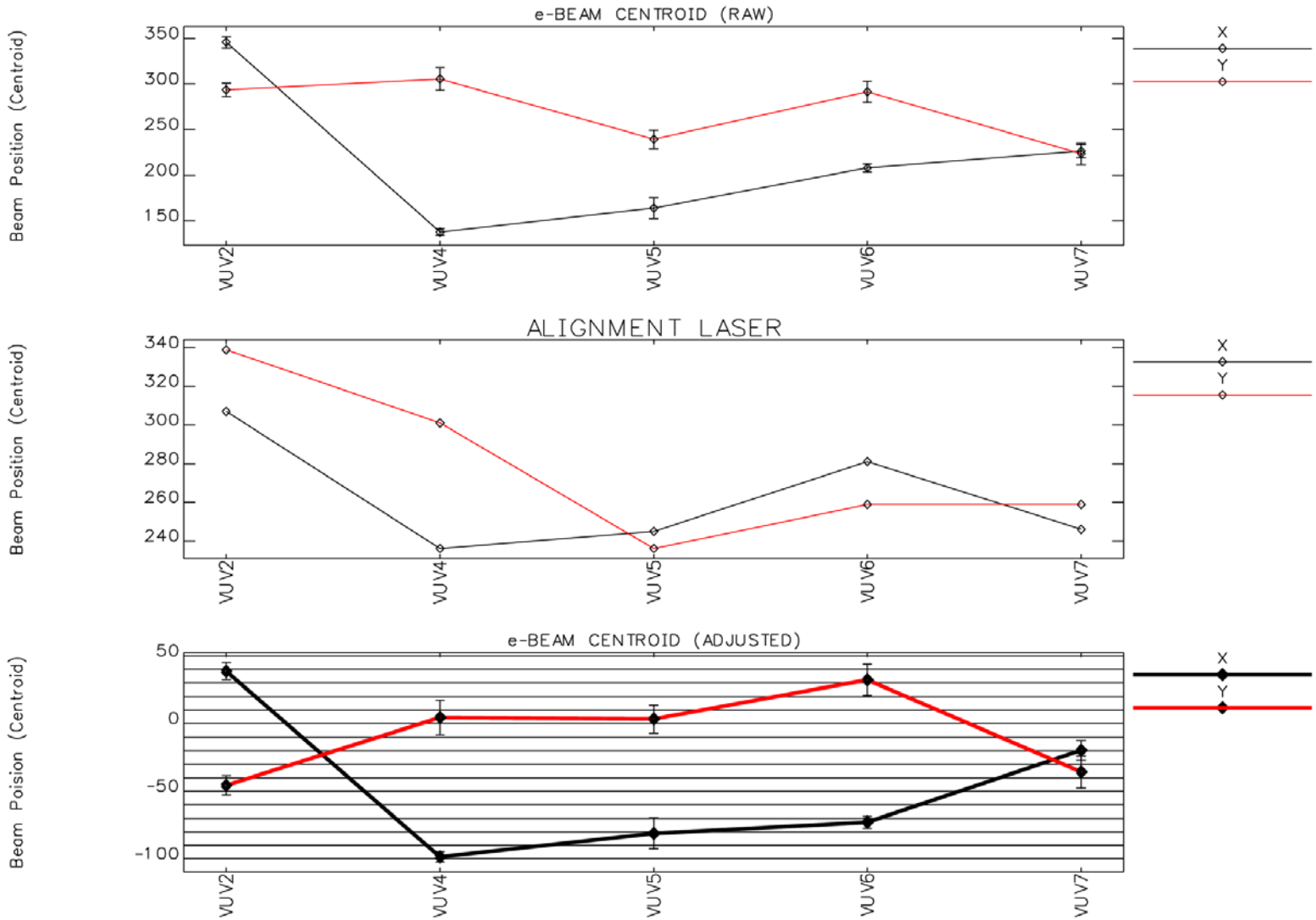
# Simulation: Results (2)



# SKE Experiment

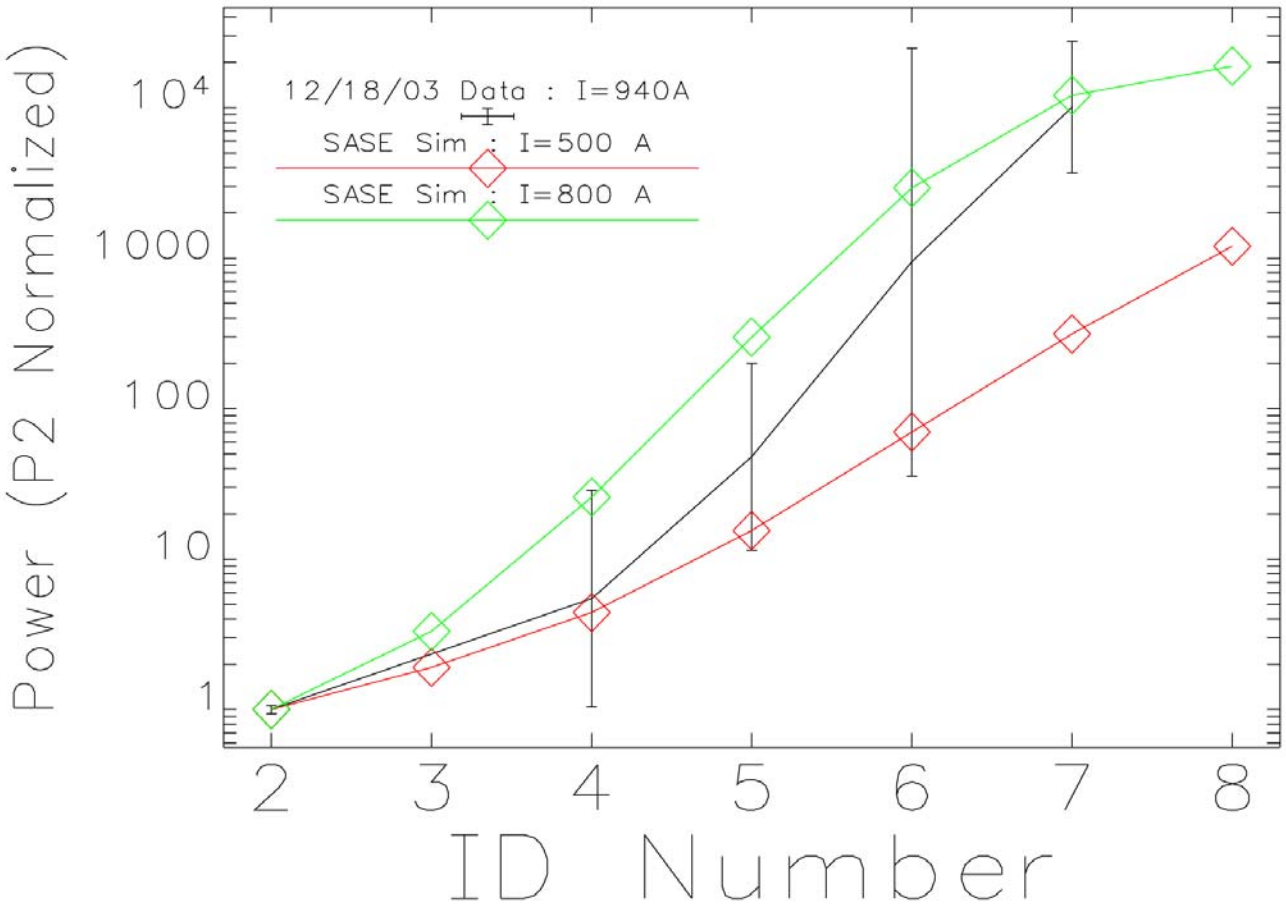
- We found that Tanaka's formula on SKE fitted the initial experimental data well.
- Also good agreements between theory and the simulation.

# A LEUTL Trajectory (12/18/03)



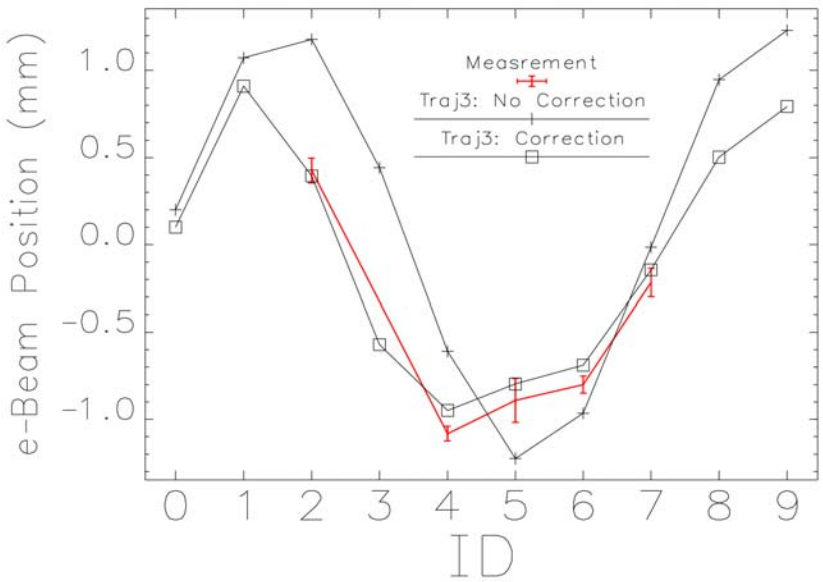

(CTR near field, 12/18/03)

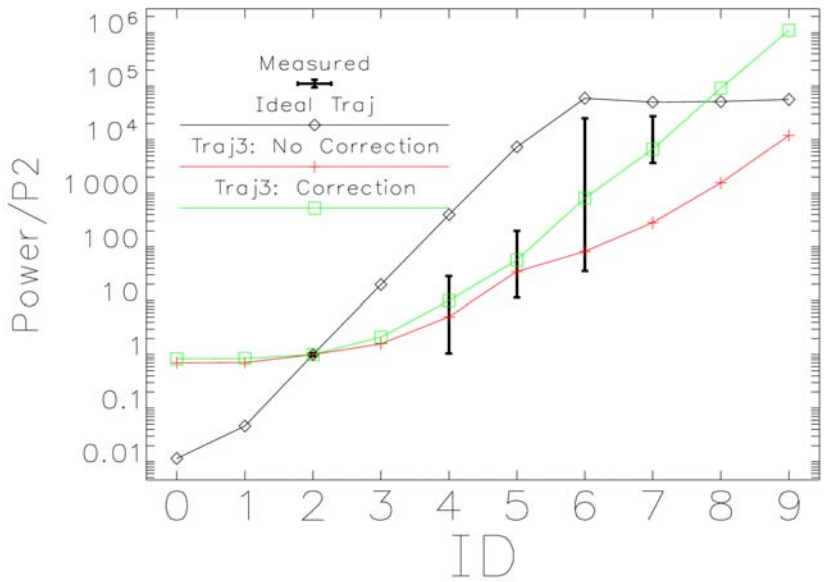
# LEUTL Trajectory Effect



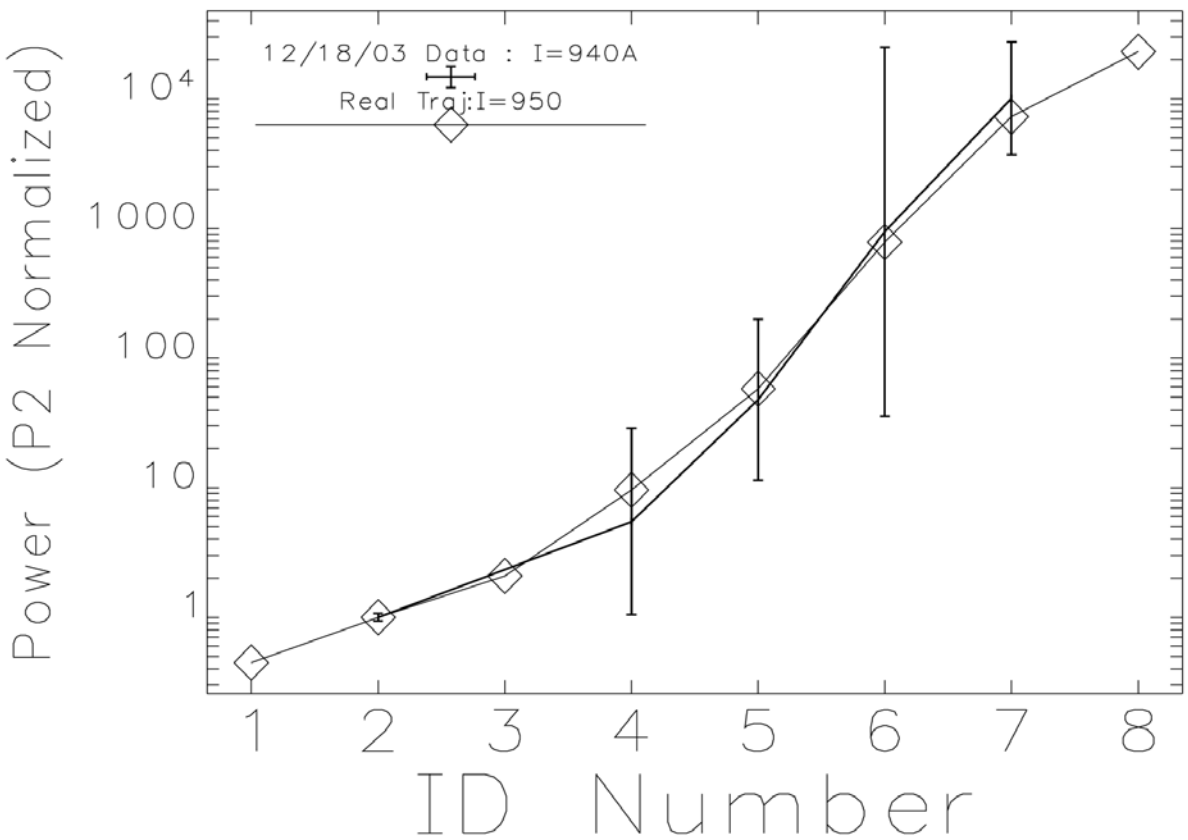
# Find Trajectory-3

(Offset Adjusted Trajectory, Large Angle)



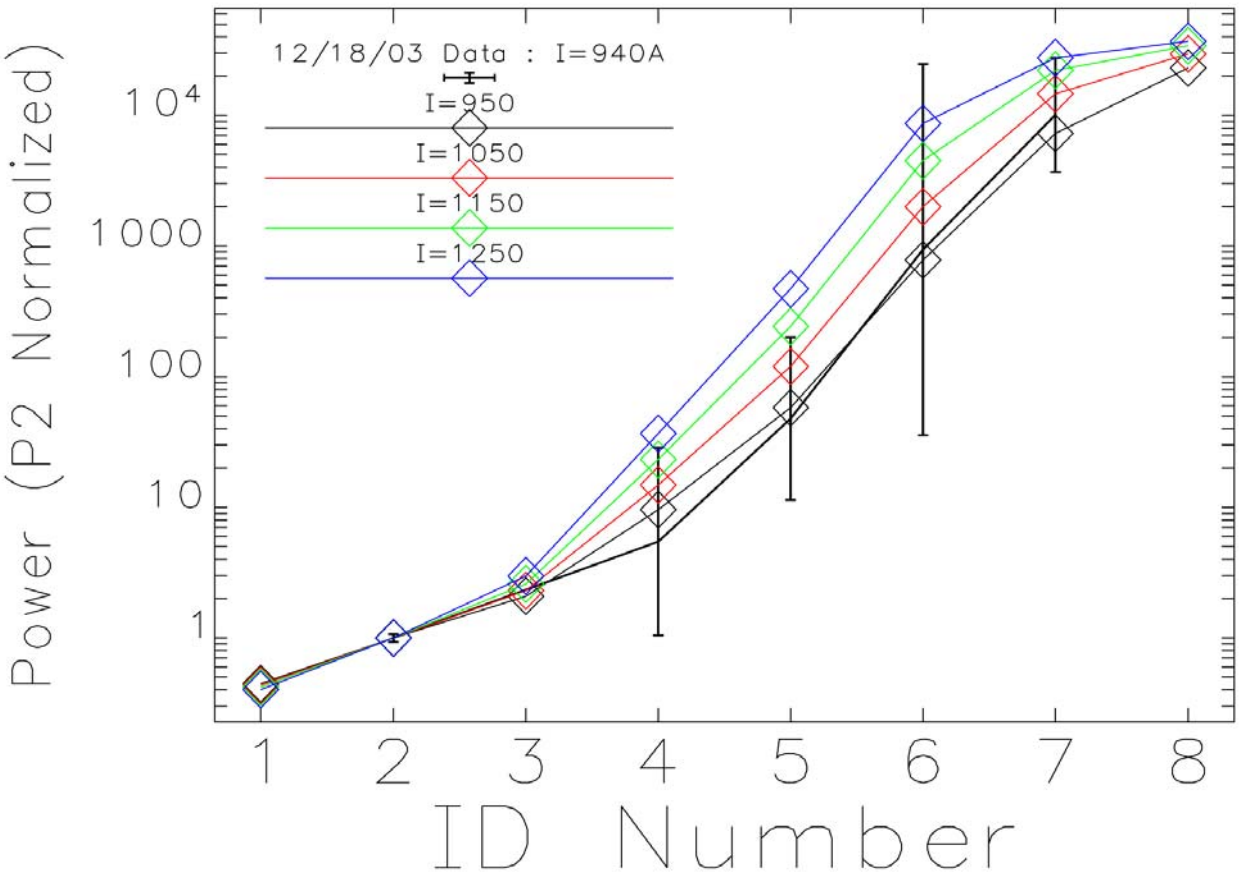
# Trajectory Found!



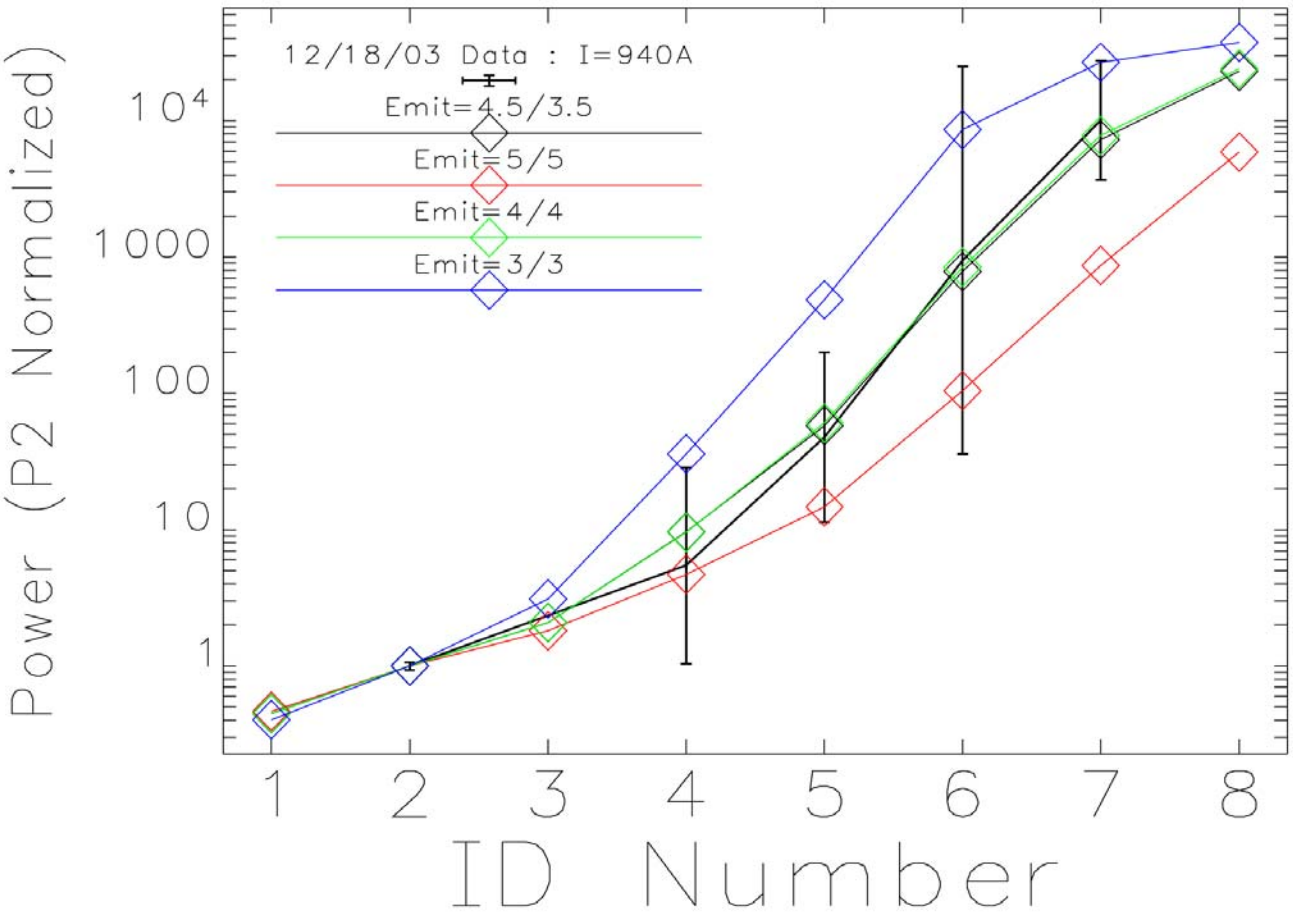

Measured Beam:
Q = 250 pC
FWHM = 250 fs
Ipeak = 940 A
EMIT = 4.5/3.5 π
ΔE/E = 0.15%

Simulated Beam:
Ipeak = 950 A

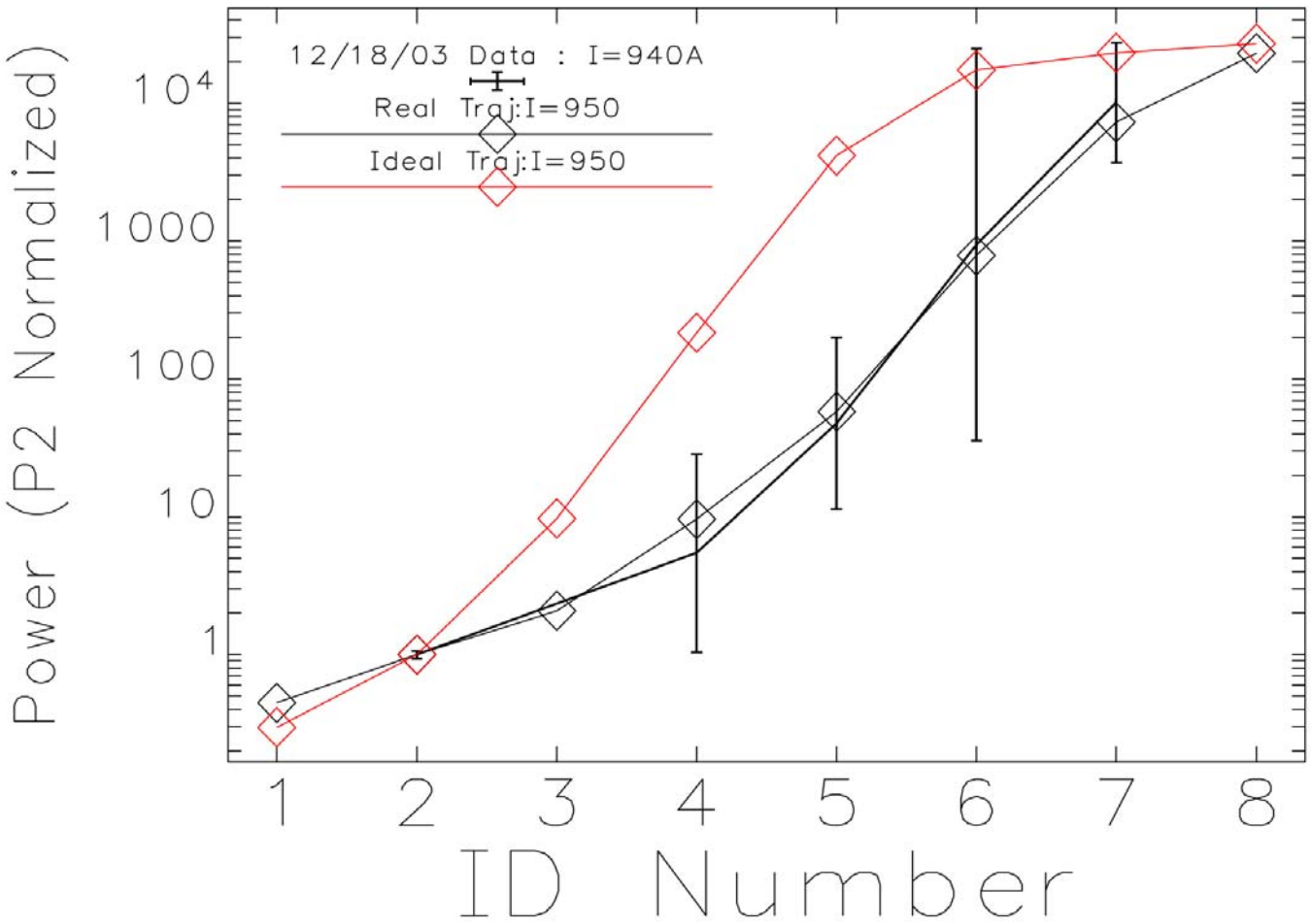
# Performance Upgrade: Ipeak



# Performance Upgrade: Emittance



# Performance Upgrade:Trajectory



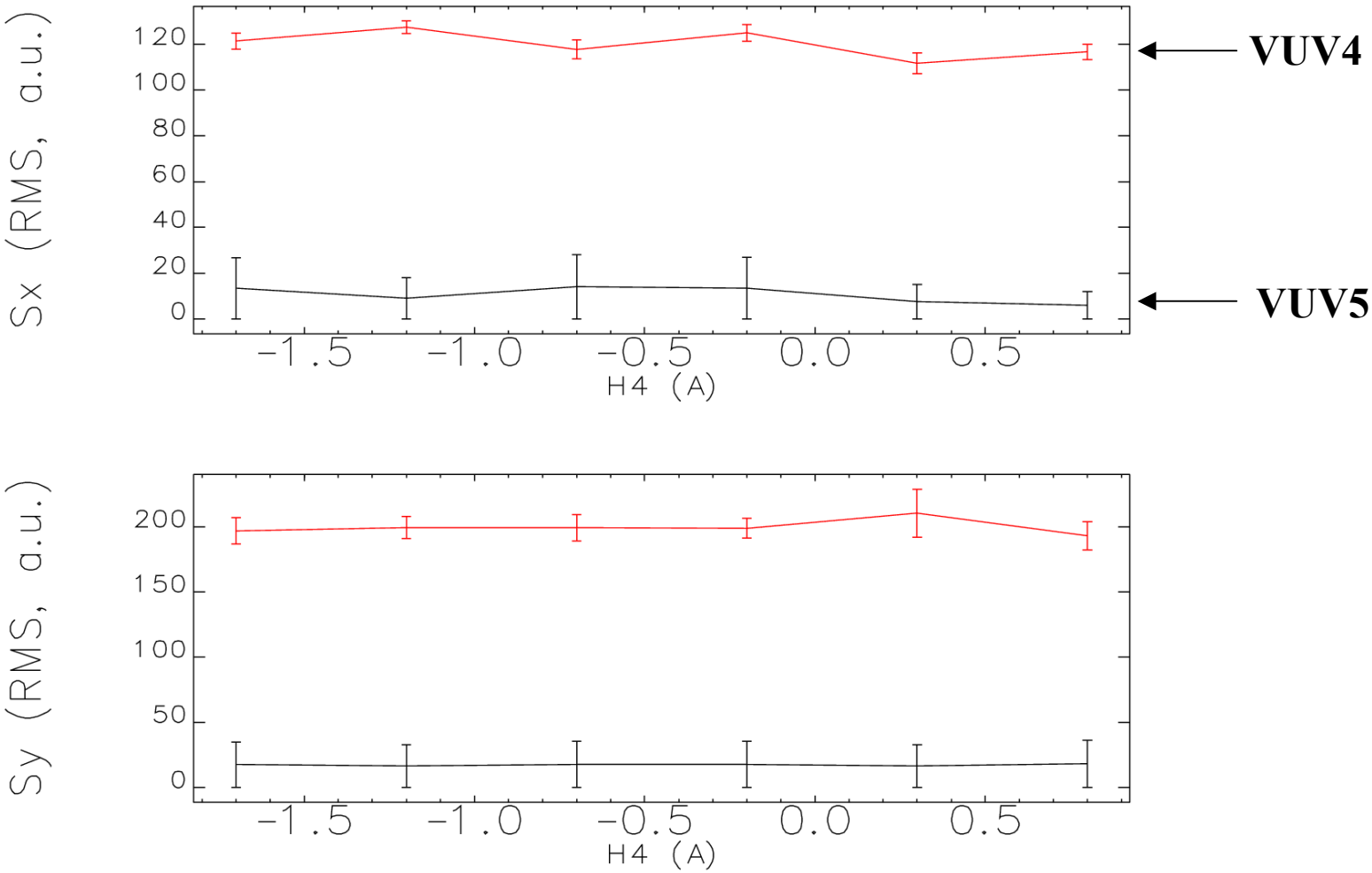
# CONCLUSION

- Single Kick Effects: Theory, Experiment, Simulation showing good agreements (we need another set of experimental data for full analysis!)
- The beam parameter on 12/18/03 was as good as we could get; the performance upgrade could be achieved by the orbit optimization.
- Optimization is most effective in small current because of the narrow-tuning-range

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

# Backup Slides

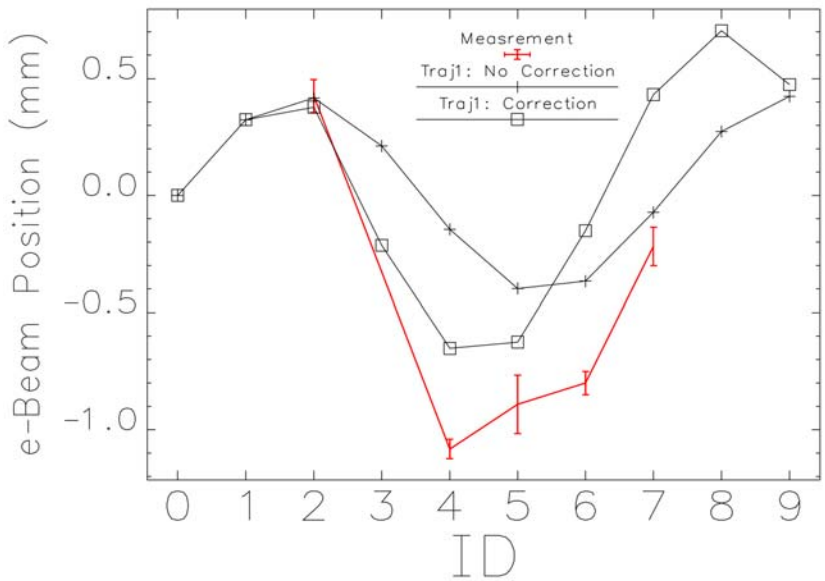
# SKE Experiment: e-Beam (3)

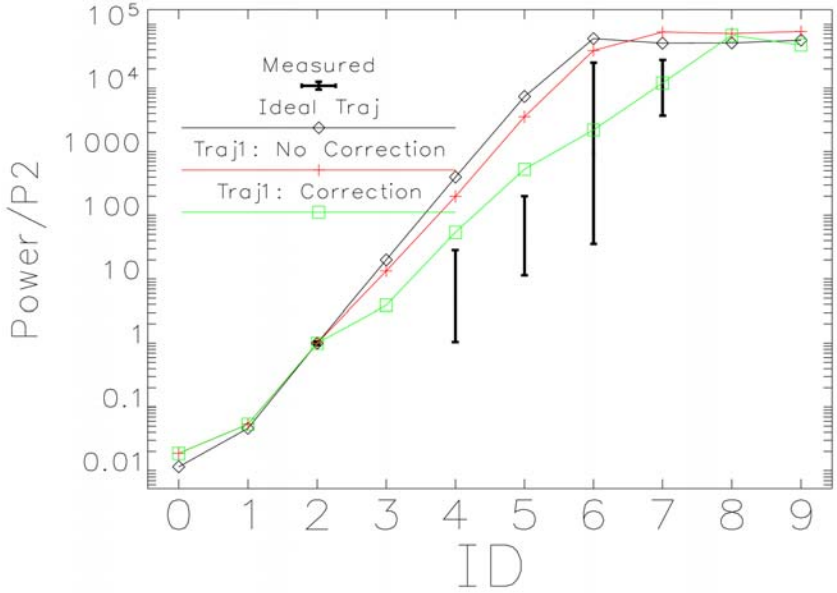



CTR near field 12/18/03

# Find Trajectory-1

(CTR Raw Data)



# Find Trajectory-2

(Offset Adjusted Trajectory, Large Amplitude)