MAGNETIC MEASUREMENTS, TUNING AND FIDUCIALIZATION OF LCLS UNDULATORS AT SLAC*

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Introduction

- LCLS is being built in collaboration of four US-DOE laboratories.
- LCLS undulator prototype and first two articles measured and tuned in ANL and shipped to SLAC.
- SLAC measurement systems tested by re-measuring undulator segments.
- New climate controlled facility constructed at SLAC to measure and tune the undulators; beneficial occupancy in June 2006, production mode in March 2007.

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Undulator Parameters

Particle energy	13.64 GeV
Radiation wavelength	1.5Å
Undulator type	Planar hybrid with canted poles
Cant angle	4.5°
Magnet material	NdFeB
Period	3cm
Gap	6.8mm (at pole's centers)
Segment length	3.4m
Number of segments	33 + 6 spares + 1 reference (40 total)
K_{eff}	3.5 ÷ 3.485 (to account for energy loss)

- Each undulator is tuned to a specific K and for an unique position
- K temperature dependence is $3 \cdot 10^{-4}$
- K is dependent on horizontal position

Tuning requirements

K_{eff}	$\pm 1.5 \cdot 10^{-4}$
First $I_{x,y}$	$< 40 \cdot 10^{-6}$ T·m
Second $I_{x,y}$	$< 50 \cdot 10^{-6}$ T·m^2
Phase errors	< 10 °
Trajectory excursion in x, y	< 2µm
Magnetic axis position in x	< 50µm
in y	< 40µm

The requirements must be met for all beam positions within ±2 mm horizontally and ±200µm vertically of the nominal beam axis.

- To meet the tolerances on the K and trajectories.
  - ➢ the MMF temperature requires to be constant at ±0.1C° level.
  - ➢ Hall probe to be calibrated to 0.5G.

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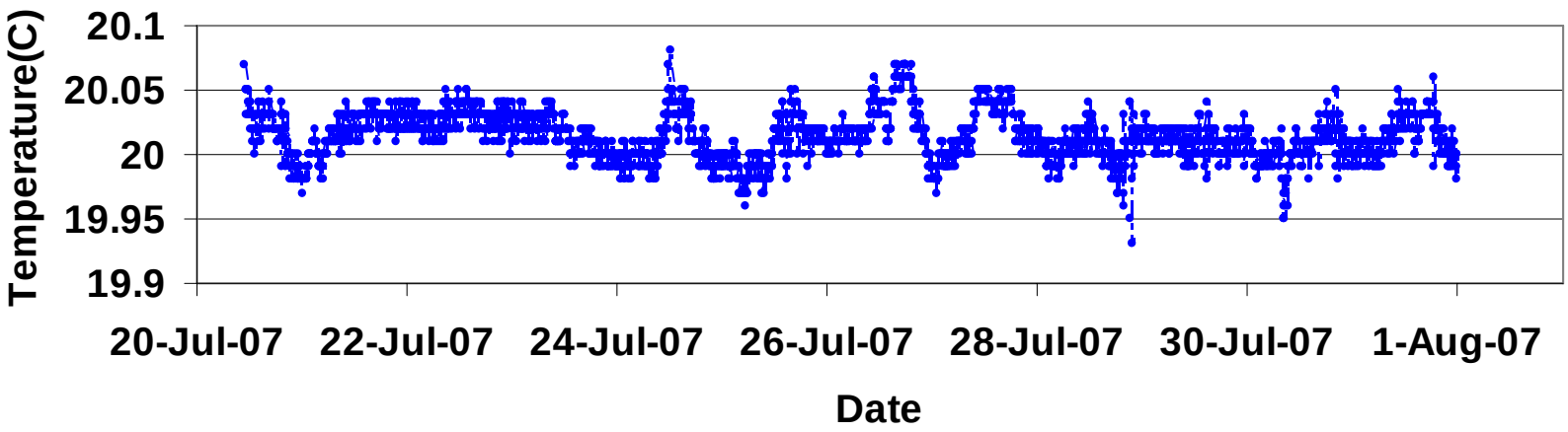
MMF ambient temperature



- Ambient temperature in MMF is constant to ±0.1˚C over a week!
- Each undulator stays inside the temperature controlled room for one week.
- The undulator temperature is monitored during the measurements and tuning by 5 sensors distributed along the length of the device.

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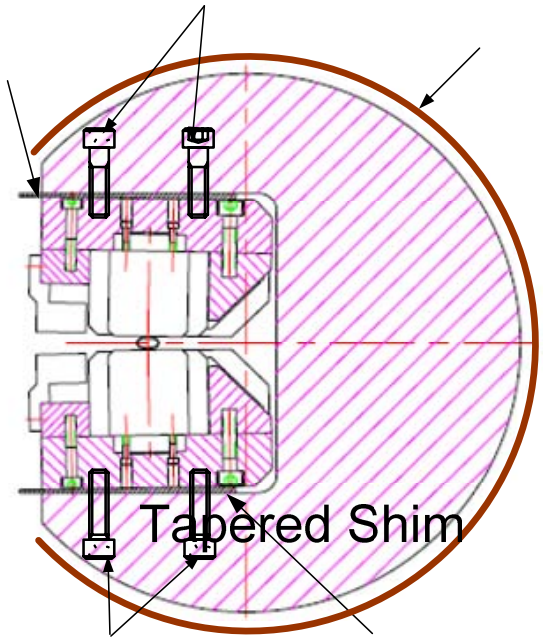
Magnetic shielding



- The difference in background magnetic fields laboratory - undulator hall is 0.1G.
- Field concentration factor is 2.4.
- Metal objects affect the ambient magnetic field.

- Each undulator is wrapped into mu-metal shield after setting the gap. It reduces the ambient field effect by a factor of 6.
- Undulator is set in the same orientation as in the tunnel, and measured on the same steel support structure.

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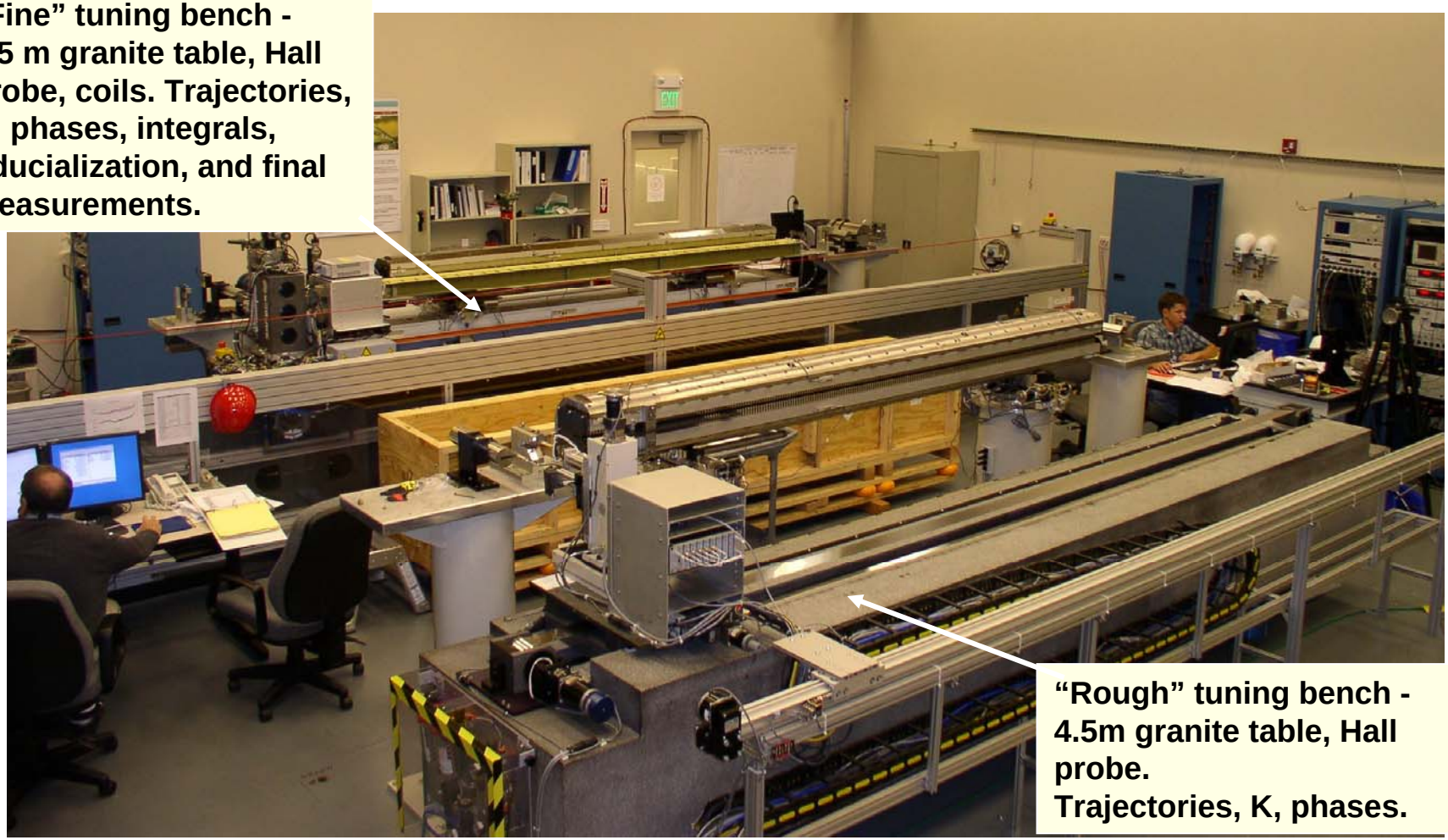
MMF tuning benches

“Fine” tuning bench - 7.5 m granite table, Hall probe, coils. Trajectories, K, phases, integrals, fiducialization, and final measurements.



“Rough” tuning bench - 4.5m granite table, Hall probe. Trajectories, K, phases.

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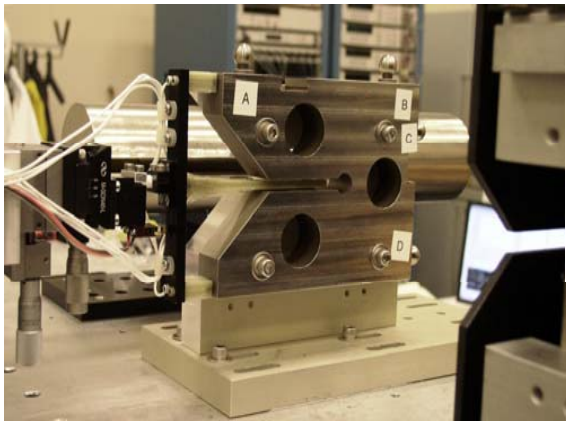
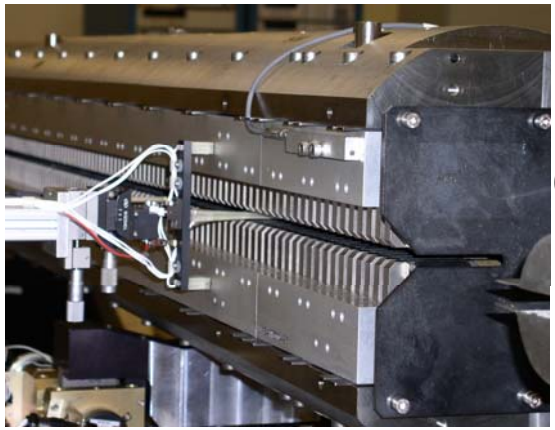
Alignment to the bench

Reference pole measurement



Undulator measurement



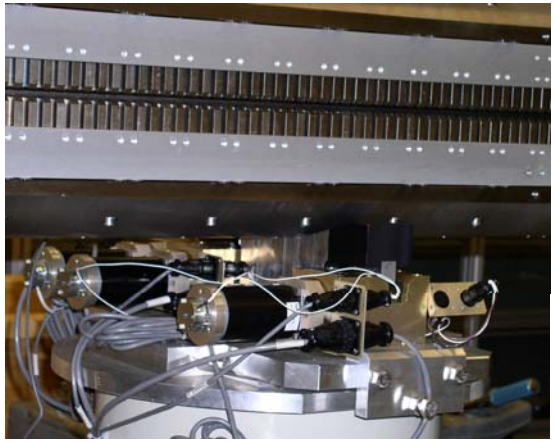
6 channels

FPGA

Triggers every 200 μm

A/D Converter
IOtech ADC 488

Done in 15 minutes



Position correction

by cam movers

PC

Apply Calibration ~10mV/μm
Calculate of X, Y, Roll, Pitch, Yaw.
Make decision:
(x, y < 5μm; roll < 100μrad; pitch, yaw < 5μrad)

Exit

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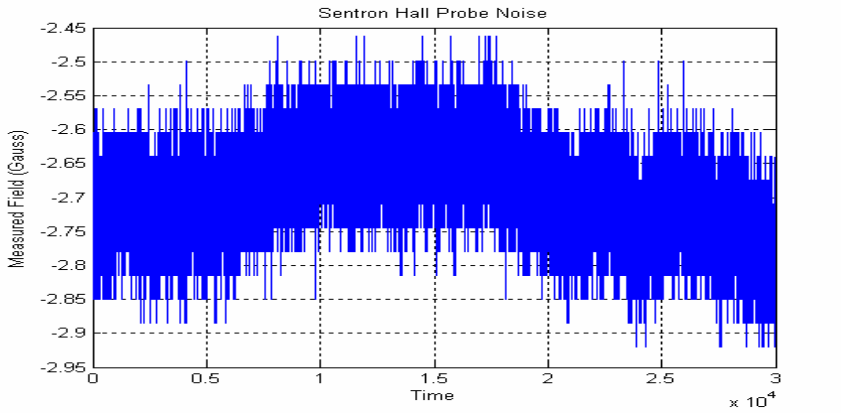
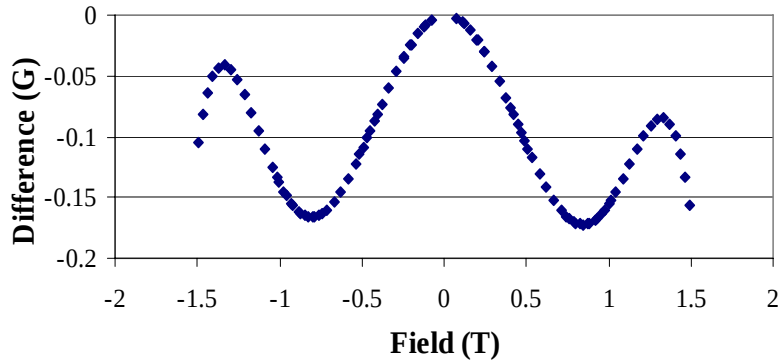
Hall probe measurements

- 2-axis Sentron XZM12-3-0.6-2T probes are used; noise ~0.2G.
- Alignment by measuring magnetic pitch and yaw; corrections by cam movers.
- Scans of magnetic field start and end inside zero field chambers.
- Sampling magnetic field every 0.2mm at 80mm/sec; Triggering by FPGA.



Calibration:

- Hall probes are calibrated by Metrolab PT2025 NMR teslameter up to 1.5T.
- A calibration stand has a chiller, set to 20˚C.
- Calibration accuracy is 0.3G



Measurements of a 3.7kG reference magnet are made periodically, to check if the probe calibration has changed.

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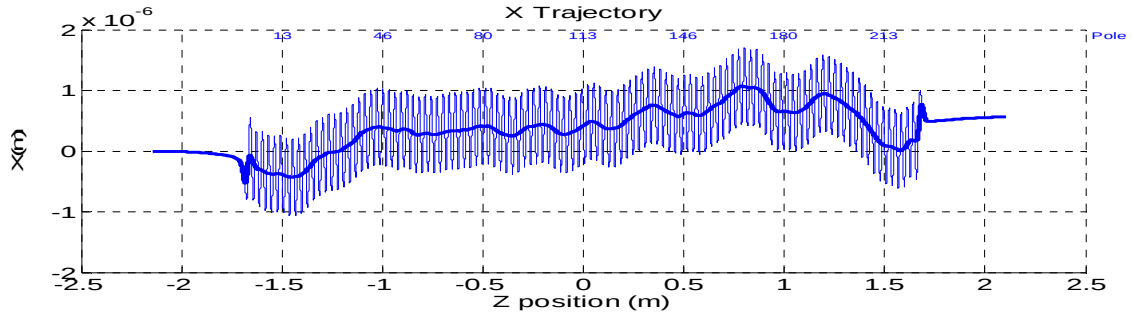
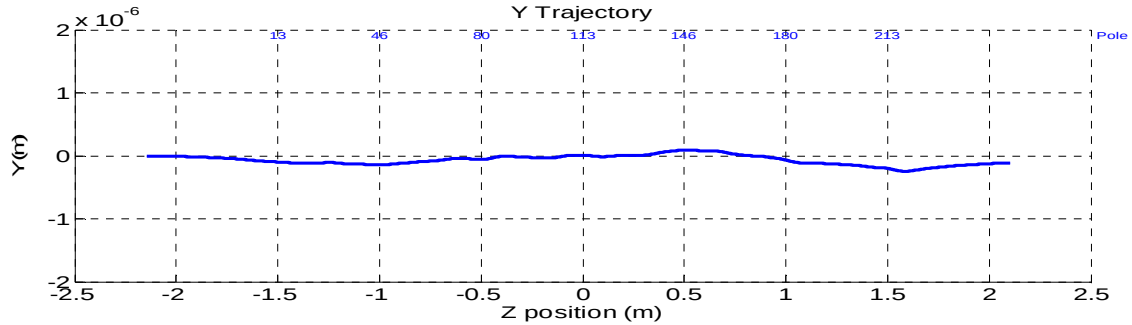
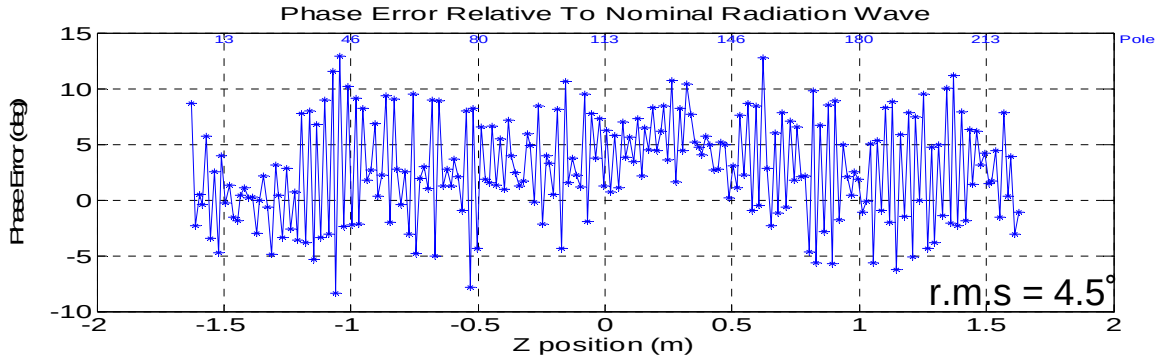
Calculated trajectories and phase errors







Phase matching is done by installing shims at the first and last few poles.

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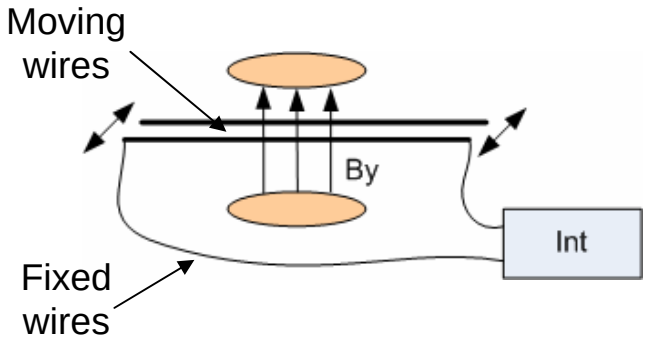
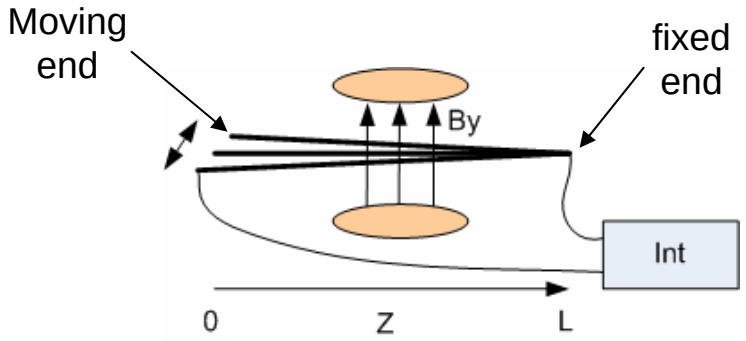
Field integral measurements*



$$I_{1y} = \int_0^L B_y\, dz = \frac{VT}{N\Delta x}$$



$$I_{2y} = \int_0^L (L - z)\; B_y(z)\, dz = \frac{VT\,L}{N\Delta x}$$

- Coil length 3.6m
- Number of turns 150
- Measurement range 0.5mm
- Accuracy $I^1_{x,y}$ $\pm 3\cdot 10^{-6}$ T ·m
  $I^2_{x,y}$ $\pm 5\cdot 10^{-6}$ T ·m^2

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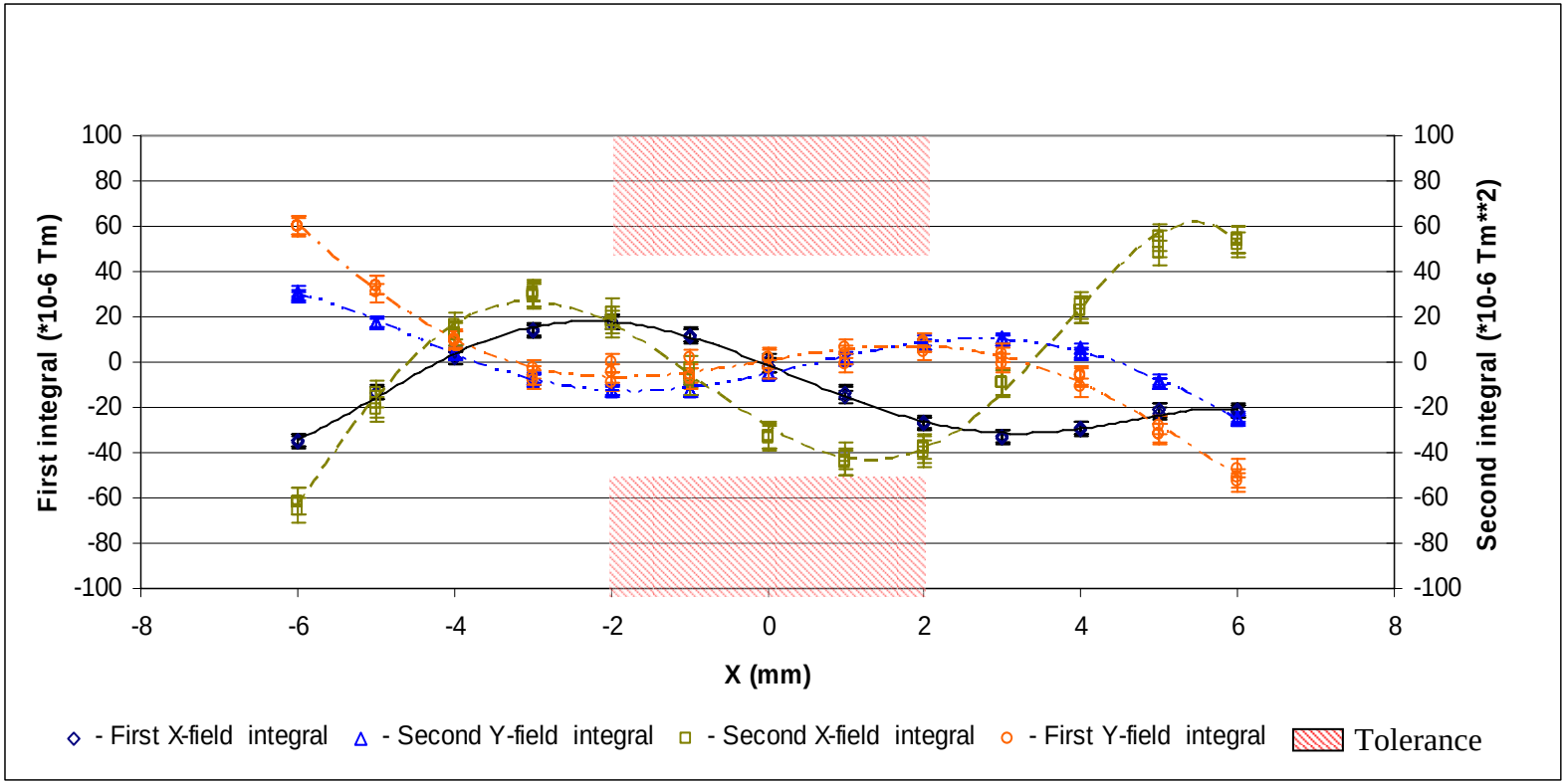
X-dependence of horizontal and vertical field integrals for undulator S/N 07



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Final data set

- Shims are glued in place before final data set is taken.
- Small corrections of order of 0.1G are applied to Hall probe measurements.

- A map of integrals is measured by the coil in a range ±6mm in 1mm steps horizontally and ±0.2mm in 0.1mm steps vertically.
- Hall probe scans are made ±6mm horizontally with 1mm steps.
- Field integral measurements and Hall probe scan are made 80mm outside the undulator (in retracted position). Background field components are measured and taken into account.

Reference undulator measurements

		May 2007	June 2007	July 2007
I^1_x (10^{-6} T·m)		+30	+20	+44
I^2_x (10^{-6} T·m^2)		-20	+4	-20
I^1_y (10^{-6} T·m)		+16	+19	+8
I^2_y (10^{-6} T·m^2)		+15	+21	+20
Phase Errors (°)	r.m.s.	3.7	3.7	3.7
	Entr.	-1.0	-1.5	-1.3
	Exit	-4.4	-4.4	-4.3
	Cell	-5.3	-5.9	-6.0
$K_{corrected}$		3.498635	3.498567	3.498483
$(\Delta K/K_{nom})$		$2\cdot10^{-5}$	$-2\cdot10^{-5}$	$-4\cdot10^{-5}$

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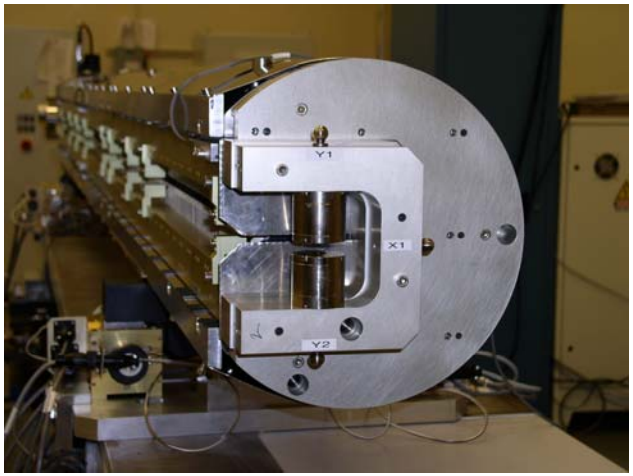
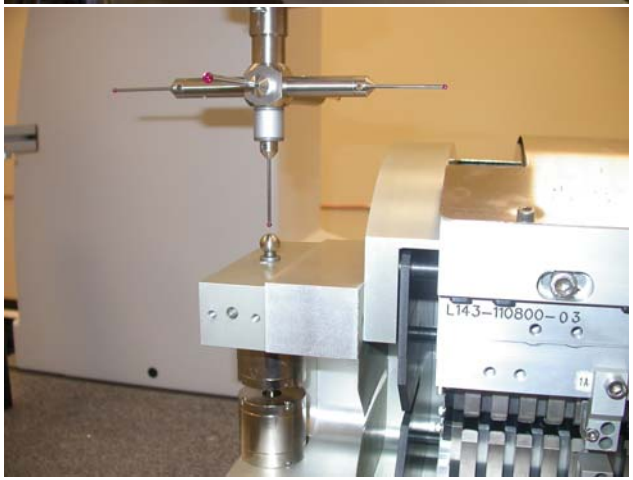
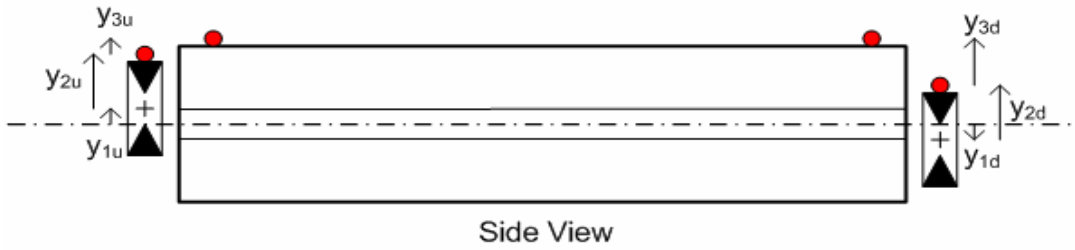
Fiducialization

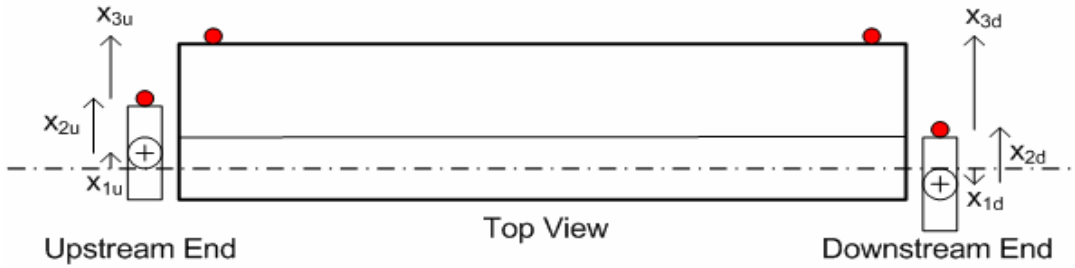




Y Fiducializaion



X Fiducialization



$$
\begin{aligned}
x_u &= x_{1u} + x_{2u} + x_{3u} \\
y_u &= y_{1u} + y_{2u} + y_{3u} \\
x_d &= x_{1d} + x_{2d} + x_{3d} \\
y_d &= y_{1d} + y_{2d} + y_{3d}
\end{aligned}
$$

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Conclusion

- All measurement systems are thoroughly calibrated and tested.
- All undulator segments are delivered to SLAC and ready for tuning.
- By August 2007, 11 undulator segments are measured and tuned to specifications in the new laboratory at SLAC.
- Throughput of the laboratory is 1 undulator per week.
- All tuning steps are well documented in a number of technical notes and available on-line.*
- Raw data and analysis results are available from SLAC web site.**

*** LCLS Technical Notes are available at www-ssrl.slac.stanford.edu/lcls/technotes.**
**** At www-group.slac.stanford.edu/met/MagMeas /MAGDATA/LCLS/Undulator/.**

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End of presentation

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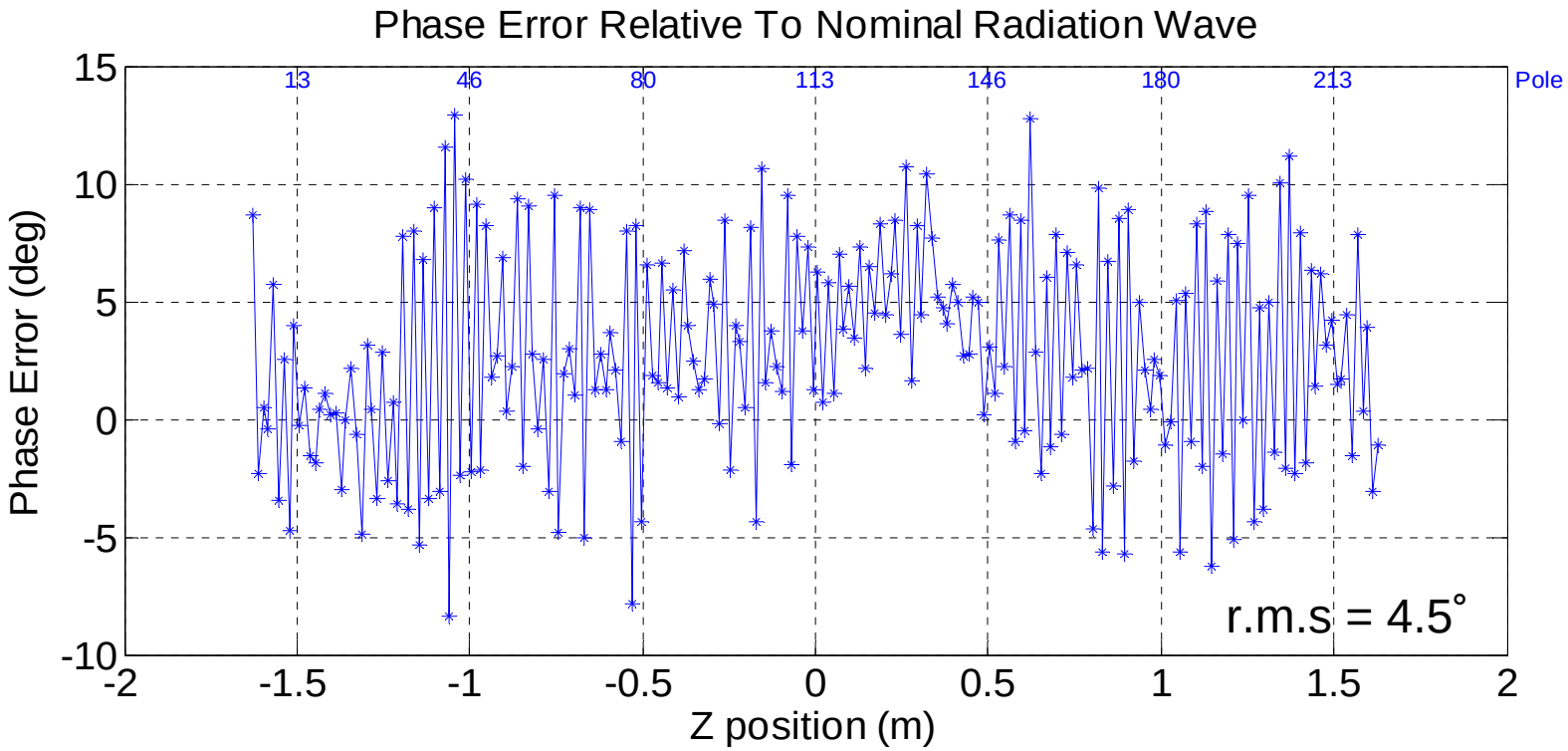
Calculated phase errors



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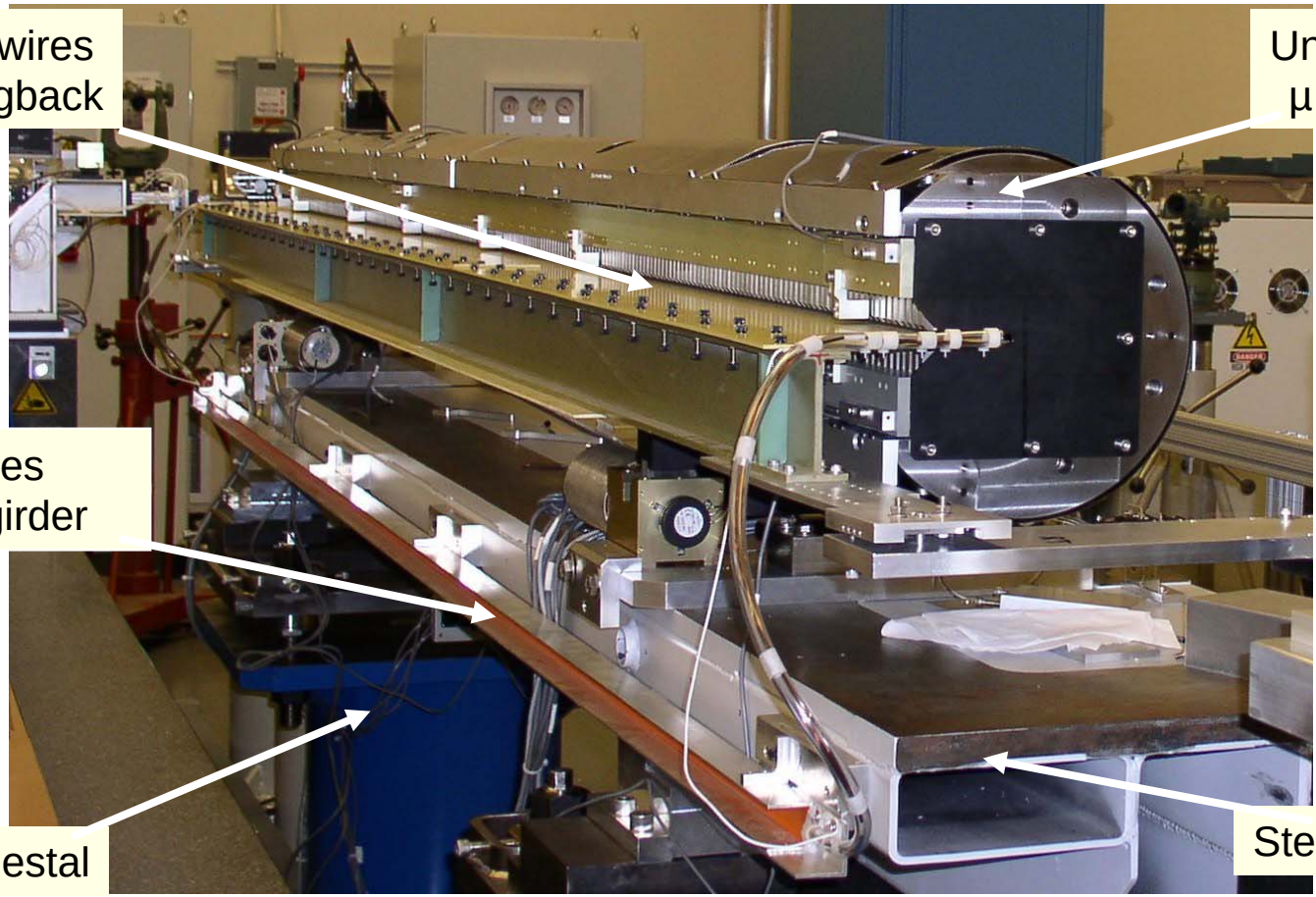
Coil measurements on fine tuning bench



X and Y field integrals are measured with the same coil!

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