LCLS Undulator Tuning And Fiducialization

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Scott Jansson, Ralph Colon, Dave Jensen

Introduction

LCLS: Linac Coherent Light Source
(Free Electron Laser)

The LCLS will consist of 33 undulator segments.
The last 1/3 of the linac is used to produce the electron beam.
Some Parameters:
E_{beam} = 13.64 Gev
λ_r = 1.5 Å
Planar permanent magnet undulators
Nd Fe B permanent magnets
λ_u = 30 mm
Gap = 6.8 mm
Tapered gap, 4.5 mrad
B_{first} = 1.249 T, tapered, nominal field, first undulator
K_{first} = 3.5, tapered, each undulator has its own K
226 poles per segment
Each segment is 3.4 m long

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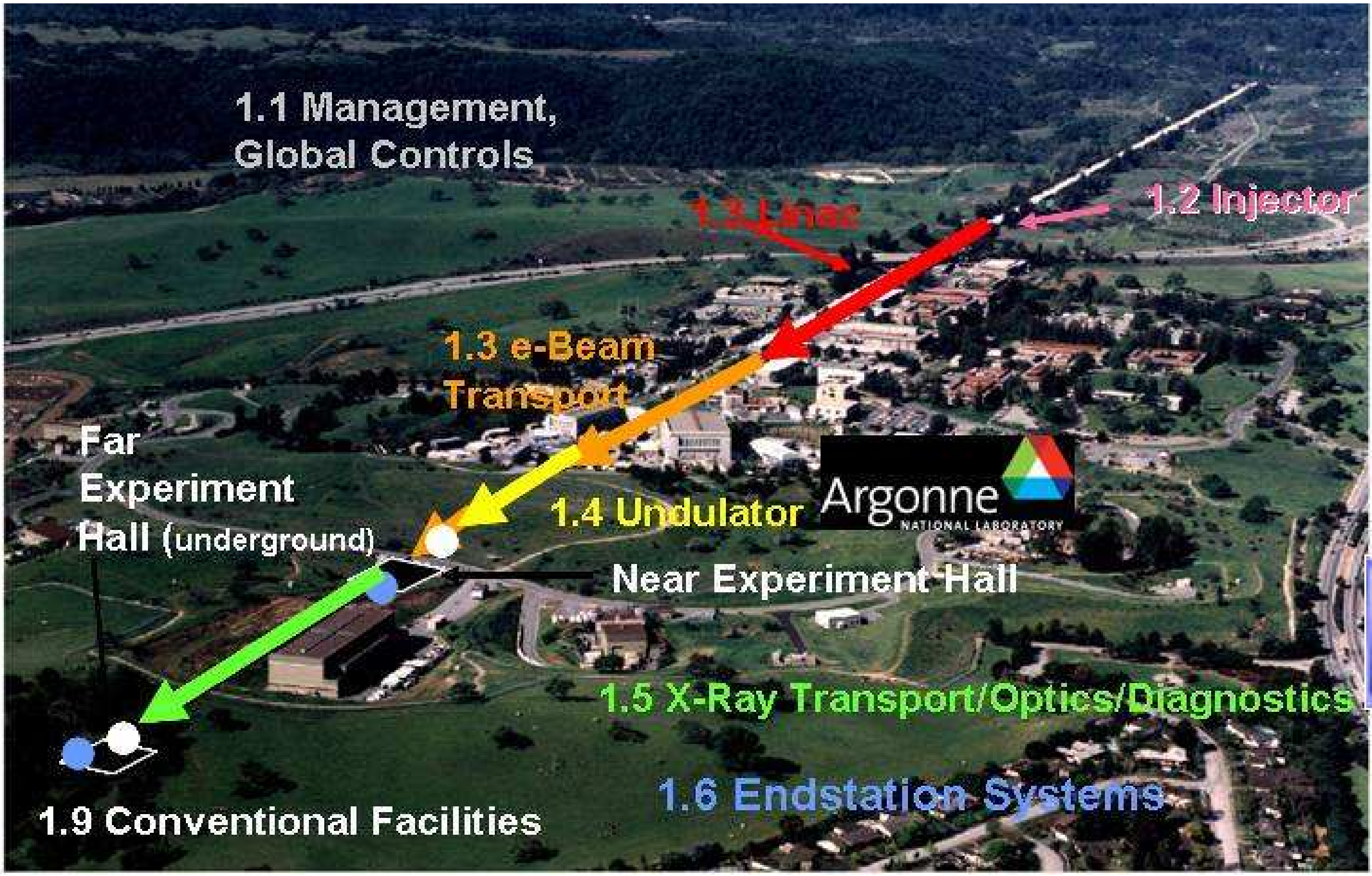
LCLS Location

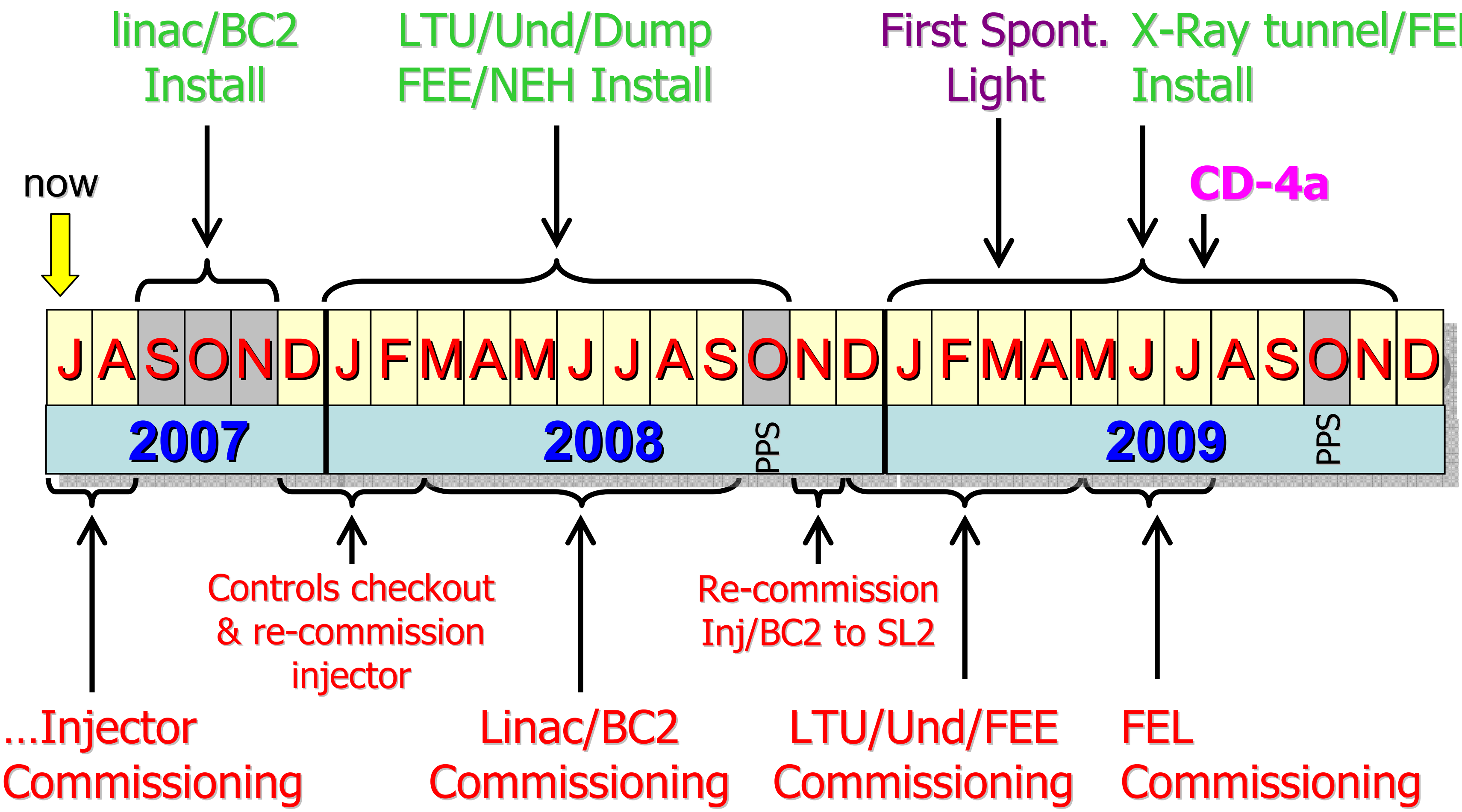


J. Galayda

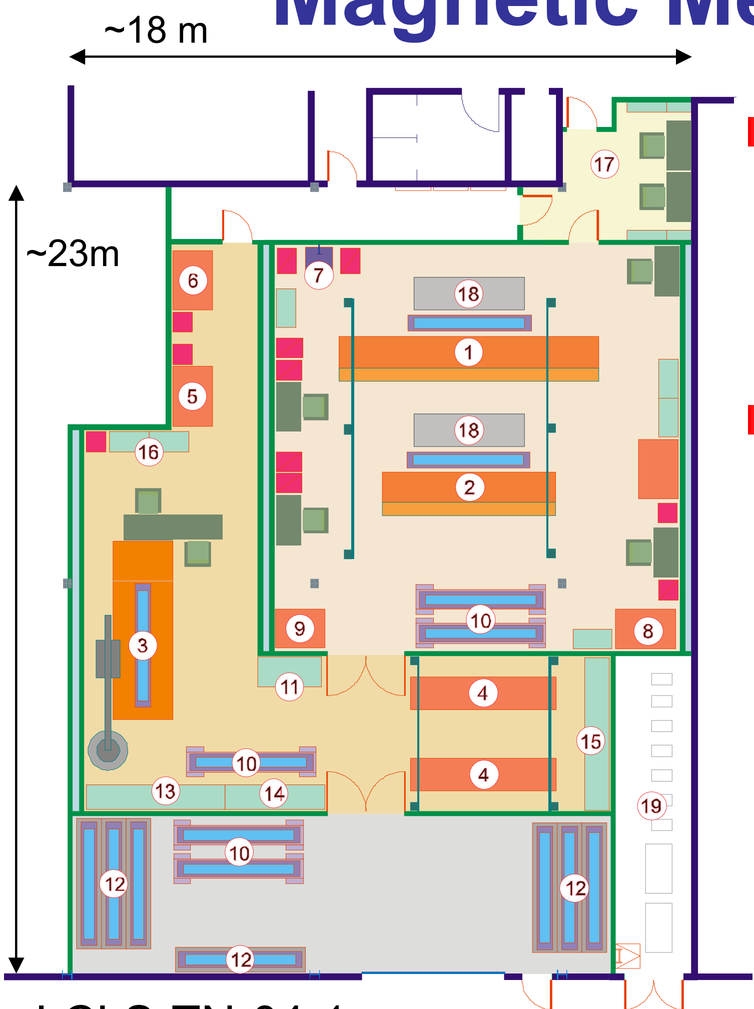
LCLS Installation and Commissioning Time-Line

June 29, 2007

Paul Emma



Magnetic Measurement Facility



LCLS-TN-04-1

- Floor plan divided into three functional areas
  - Magnetic Measurements (± 0.1° C)
  - Fiducialization and Assembly (± 1° C)
  - Storage (± 2.5° C)
- Test stand lay-out is driven by requirement to match the Earth Magnetic Field conditions in lab to Undulator Hall, i.e. azimuth and gap orientation need to be identical

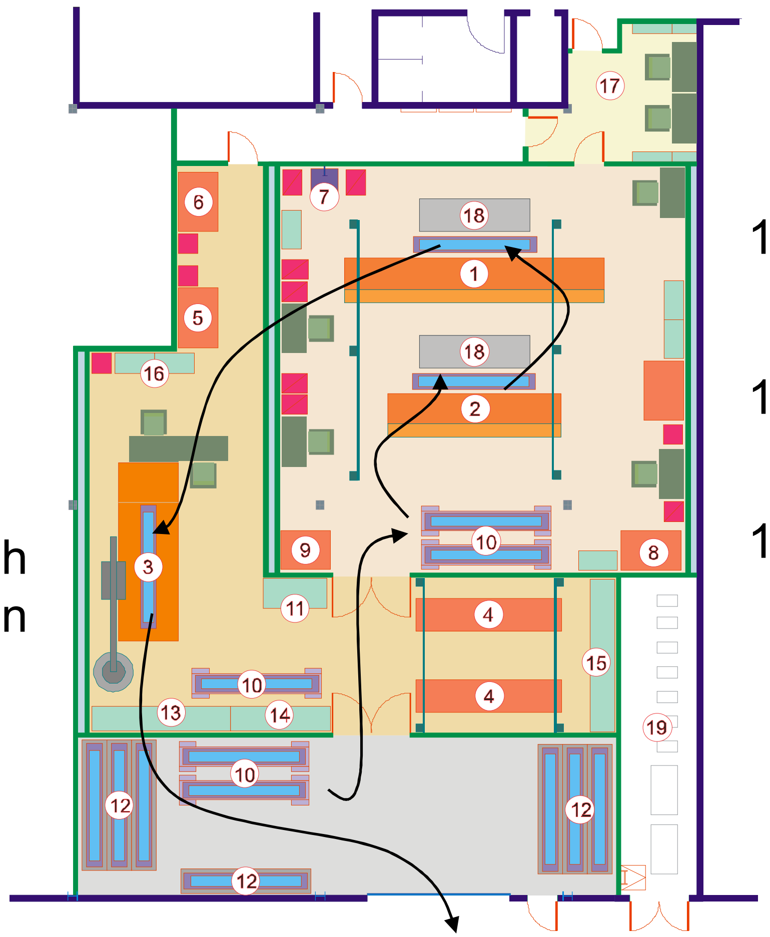
1. Test Stand #1
2. Test Stand #2
3. Fiducialization CMM
4. Cradle Assembly
5. Quad Fiducialization
6. Quad Field Meas.
7. Hall Probe Calibration
8. BPM Fiducialization
9. Needle Fixture Calibr.
10. Und. Seg. / Cradle on Transport Cart
11. Inspection Tools
12. Und. Segment Storage (3 x 4)
13. Vacuum Chamber Storage
14. Quad. / BPM Storage
15. Cradle Storage
16. CMM Tools Storage
17. Office
18. Tuning Platform
19. HVAC Equipment

Undulator Movements In MMF

Tuning Time:
about 4 weeks

<1 Week, Finish
Fiducialization

Peak Throughput:
1 undulator per week

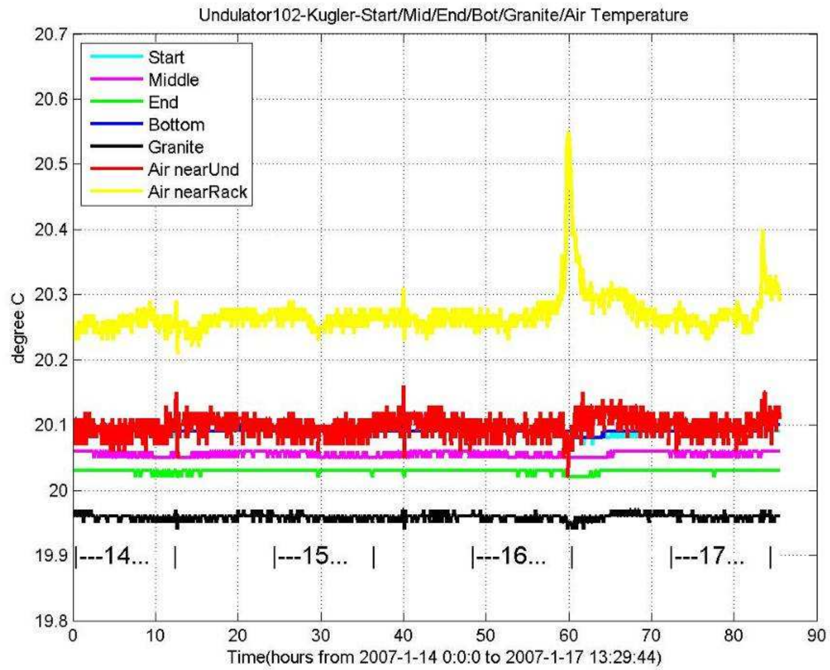


1 Week, Fine Tuning

1 Week, Rough Tuning

1 Week, Come to 20 C

MMF Temperature

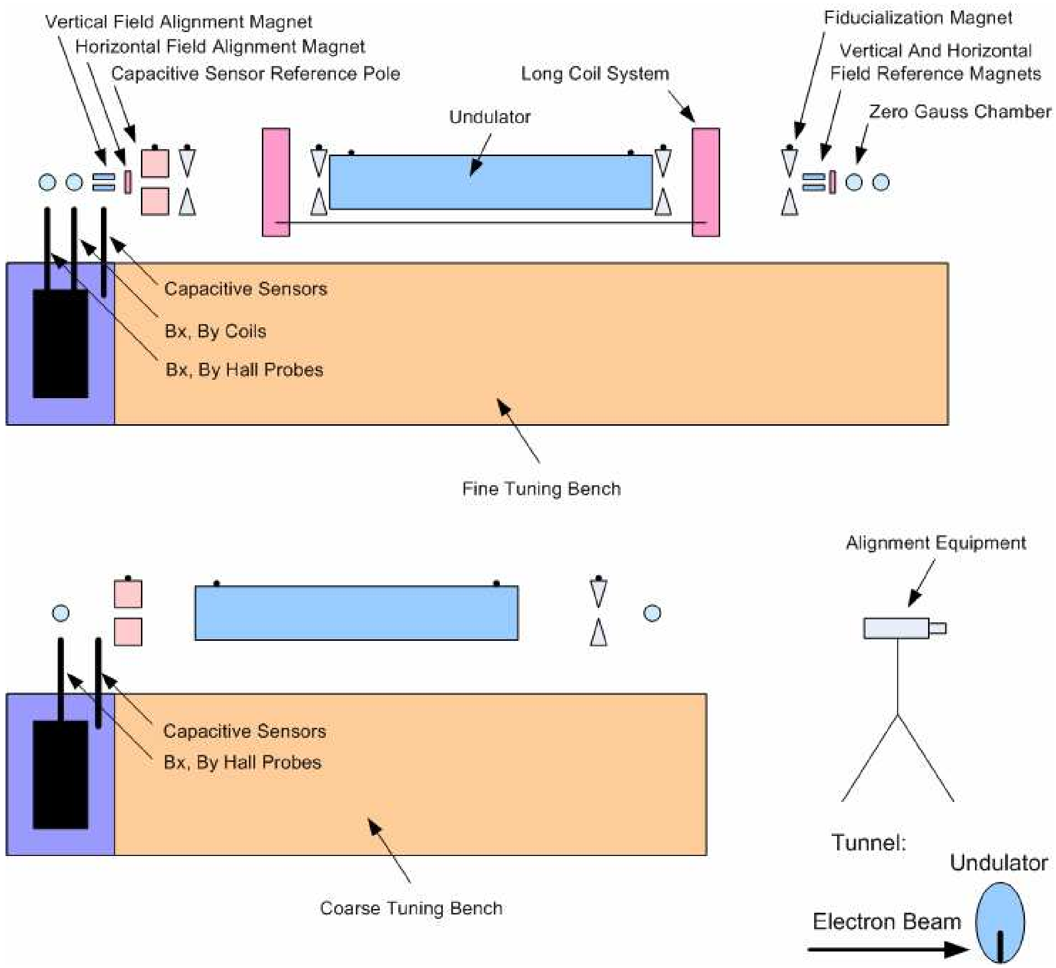


Achim Weidemann

Time history at the Kugler bench

In general, the system meets stability requirements

Rough Tuning Bench Components



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Rough Tuning Bench

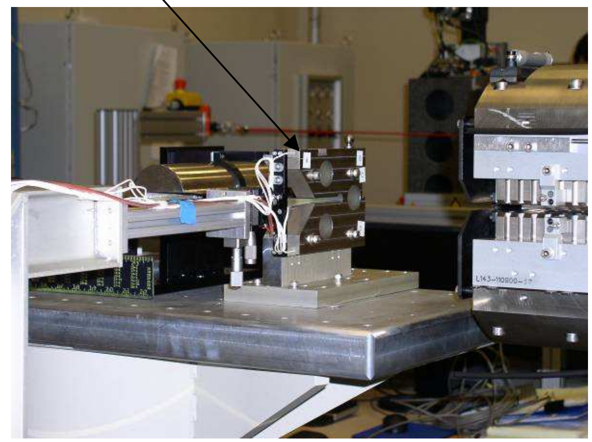
Undulator

Cam Movers

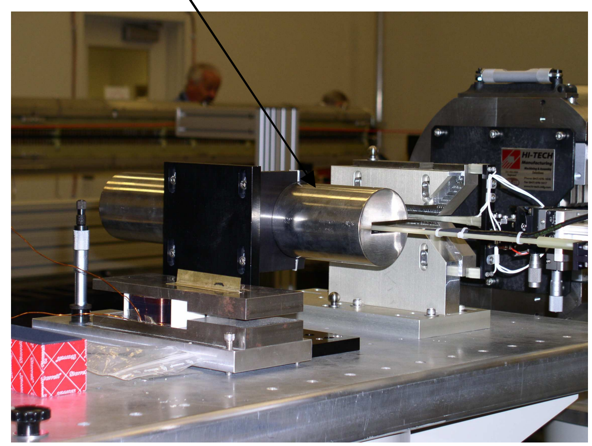
Cable Handling

Bench

Reference Pole



Zero Gauss Chamber



Capacitive Sensor Alignment Performance

Cam mover-capacitor sensor system check
First try

	x(mm)	y(mm)	roll(mrad)	pitch(mrad)	yaw(mrad)	time
initial	0.105	-0.356	-2.128	-0.189	-0.55	14:13
1-st	0.027	-0.032	-0.177	-0.017	-0.393	14:14
2-d	0	0.014	-0.004	-0.002	-0.031	14:24
3-d	0.011	-0.004	0.015	-0.001	-0.001	14:28

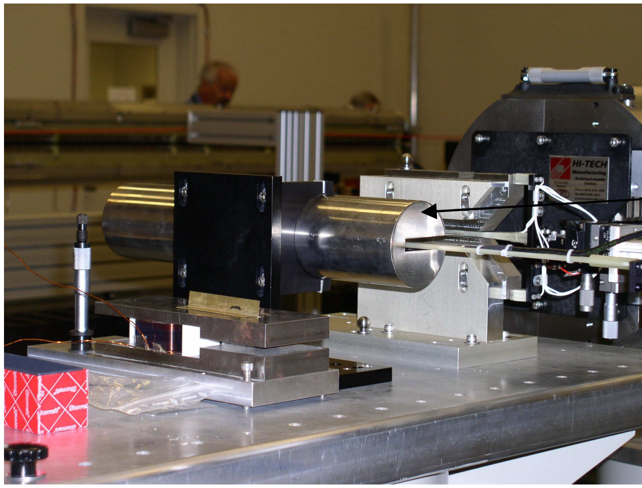
Second try, next day

	x(mm)	y(mm)	roll(mrad)	pitch(mrad)	yaw(mrad)	time
Init	0.004	0.138	2.06	0.165	0.402	8:58
1-st	-0.012	0.064	0.023	0.021	0.109	9:01
2-nd	-0.008	0.0	-0.001	0.003	0.028	9:05
3-rd	-0.002	0.0	0.004	0.001	0.007	9:08
Rep.3	0.001	0.0	-0.006	-0.001	0.007	9:11

Undulator mechanically aligned to bench in 15 minutes

Yurii Levashov

Scans Begin And End In A Zero Gauss Chamber



Beginning zero field measurement

Ending zero field measurement

Sentron Hall probe

Amuneal Chambers

Zero Offset Correction
Assume linear offset dependence on time

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Undulator Tuning

Rough Tuning Steps:
straighten trajectories
set gap (set K and tune phase)
do phase shimming
do phase matching
add magnetic shield

Fine Tuning Steps:
check trajectories, phase
adjust field integrals
shim field uniformity
glue shims in place
perform checks
make final data set
fiducialize

LCLS-TN-06-17
- Gives requirements
- Describes equipment
- Enumerates each step of tuning
- Describes output data

pos	γ	Keff
1	26692.70	3.500000
2	26690.65	3.499557
3	26688.61	3.499114
4	26686.34	3.498623
5	26684.30	3.498180
6	26682.25	3.497737
7	26679.99	3.497246
8	26677.94	3.496803
9	26675.90	3.496360
10	26673.63	3.495869
11	26671.59	3.495426
12	26669.54	3.494984
13	26667.27	3.494492
14	26665.23	3.494049
15	26663.19	3.493607
16	26660.92	3.493115
17	26658.88	3.492672

pos	γ	Keff
18	26656.83	3.492230
19	26654.56	3.491738
20	26652.52	3.491296
21	26650.48	3.490853
22	26648.21	3.490361
23	26646.17	3.489919
24	26644.12	3.489476
25	26641.85	3.488984
26	26639.81	3.488542
27	26637.77	3.488099
28	26635.50	3.487608
29	26633.46	3.487165
30	26631.41	3.486722
31	26629.14	3.486231
32	26627.10	3.485788
33	26625.06	3.485345

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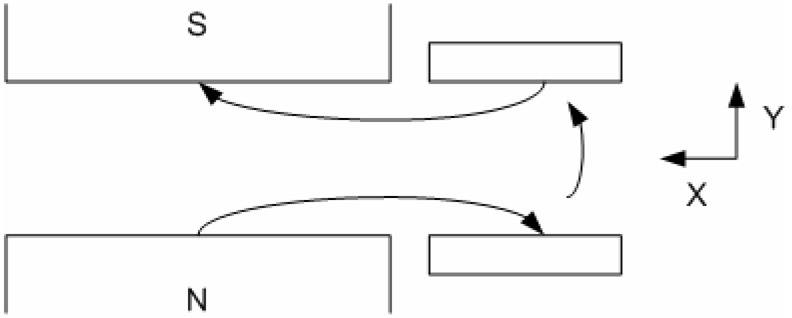
X Trajectory Shims

Isaac Vasserman's Ideas

ANL/APS/TB-48

ANL/APS/TB-48



LCLS-TN-04-7

- Apply shims to top and bottom poles
- Shims weaken By, don't cause Bx
- Can't strengthen pole, instead place shims on next pole to reduce deflection in other direction

- Developed software to automate shim placement

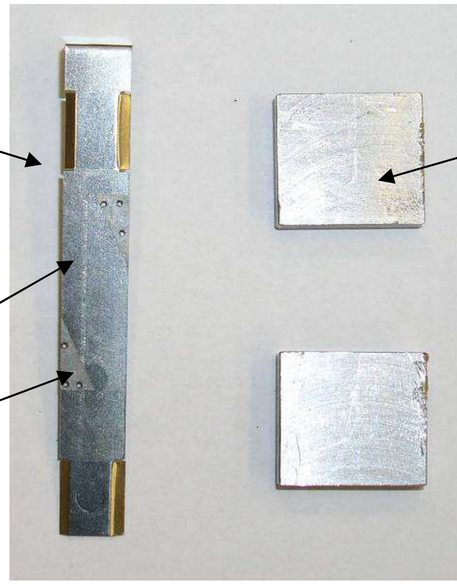
Y Trajectory Shims

Bx Shim
New Design

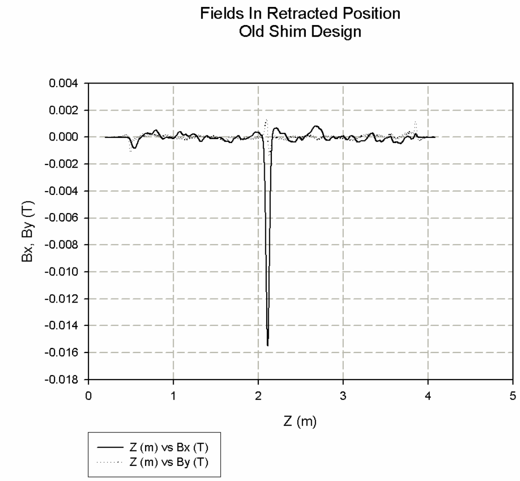
Smaller external fields
Uniform Bx field in gap

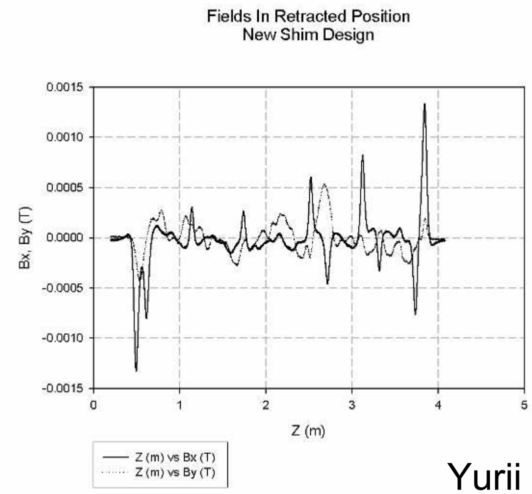
Inconel

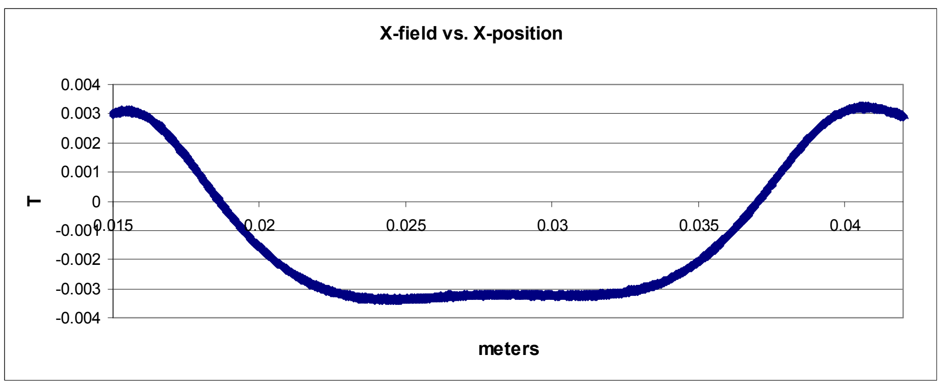
Steel
Spot weld



Old
Shim
Design



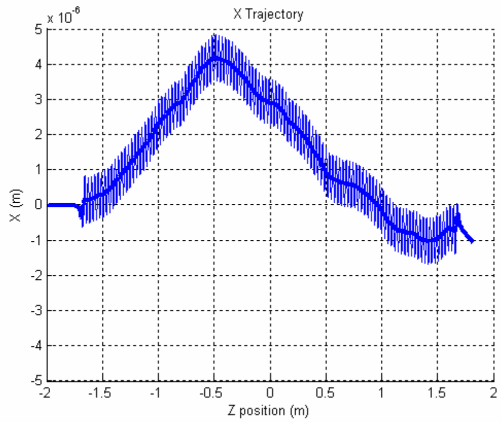




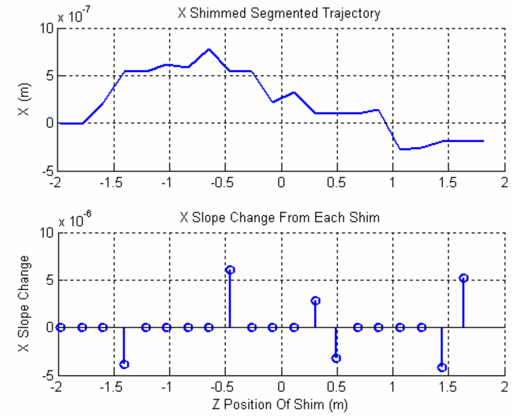
Yurii Levashov

Straighten X And Y Trajectories

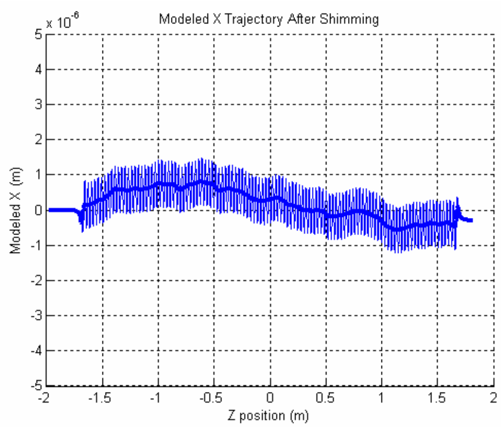
Measured X Trajectory



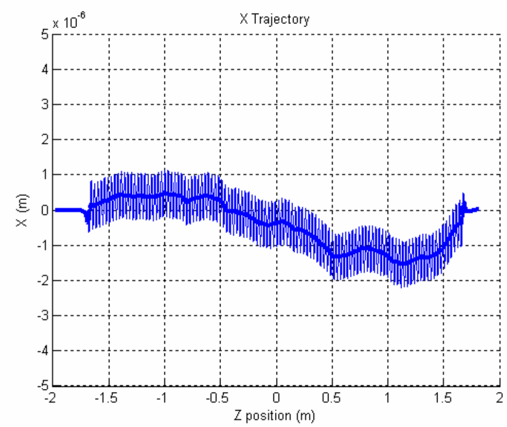
Calculate Shims



Modeled X Traj With Calc Shims



Measured X Traj After Calc Shims Applied



The Shimming Is Automated

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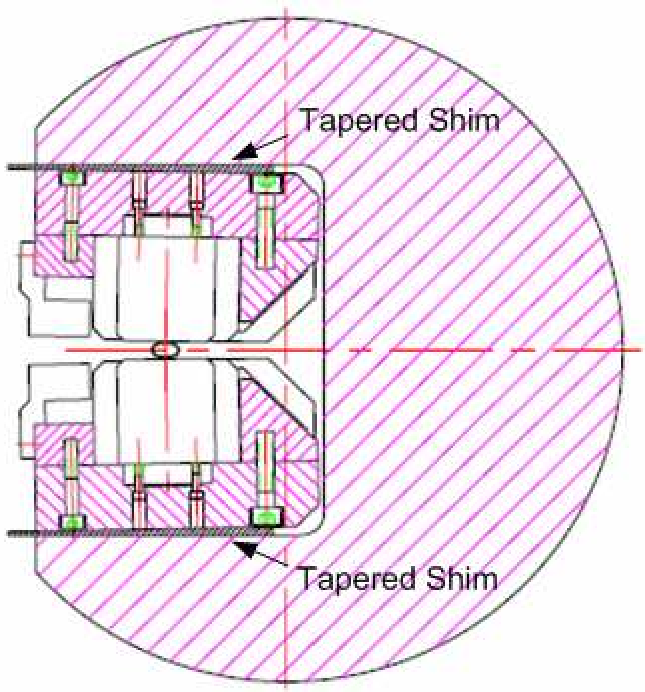
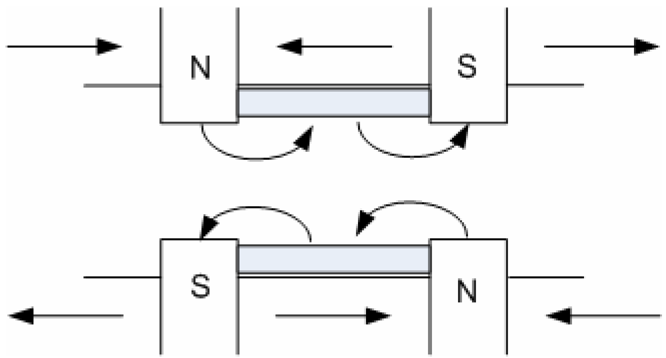
Gap Shims



Tapered shims give the pole cant angle and are used to set the gap.

Phase Shims



LCLS-TN-04-7

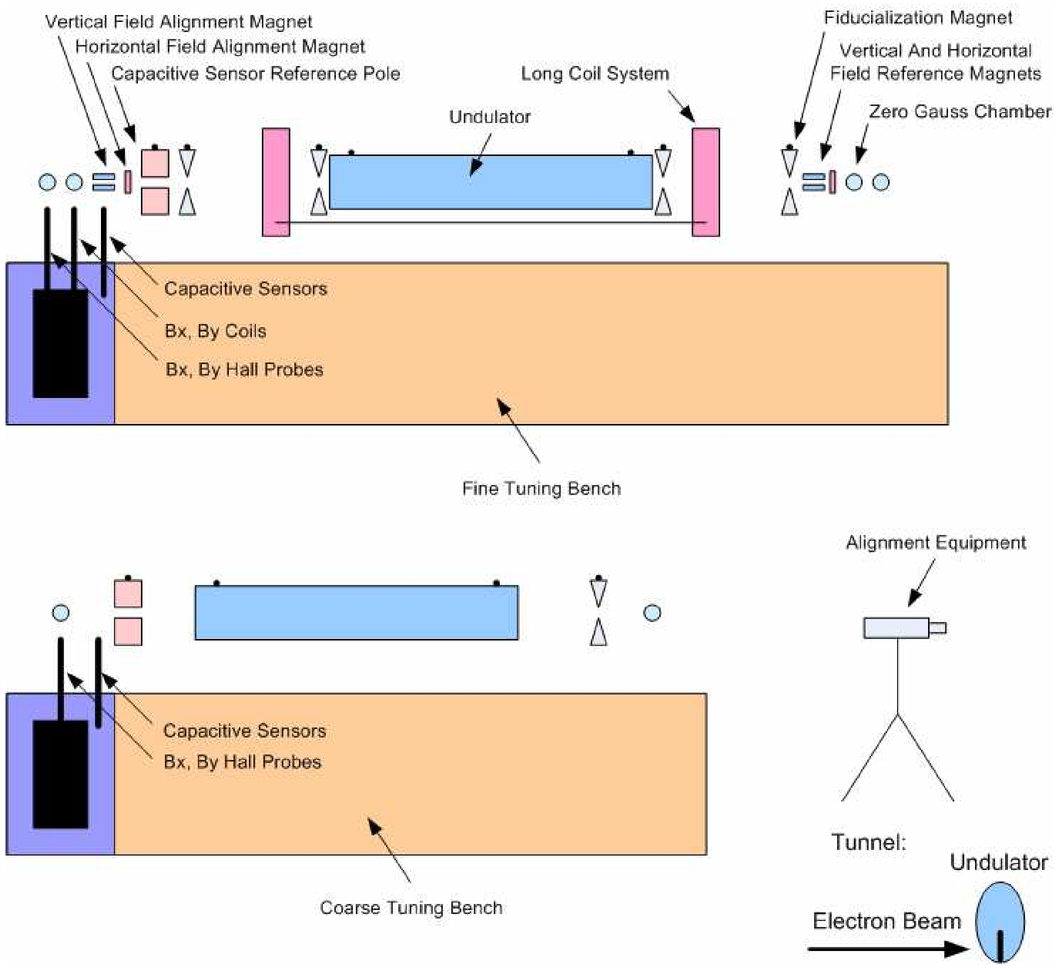
ANL/APS/TB-48

- Measure By with a Hall probe
- Calculate phase error
- Calculate shims to correct error
- Apply shims, repeat

- Developed software to automate shim placement

- We don't have shims to strengthen a magnet, only weaken
- Must locally reduce the gap to increase phase shift

Fine Tuning Bench Components



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Fine Tuning Bench

Undulator With Magnetic Shield

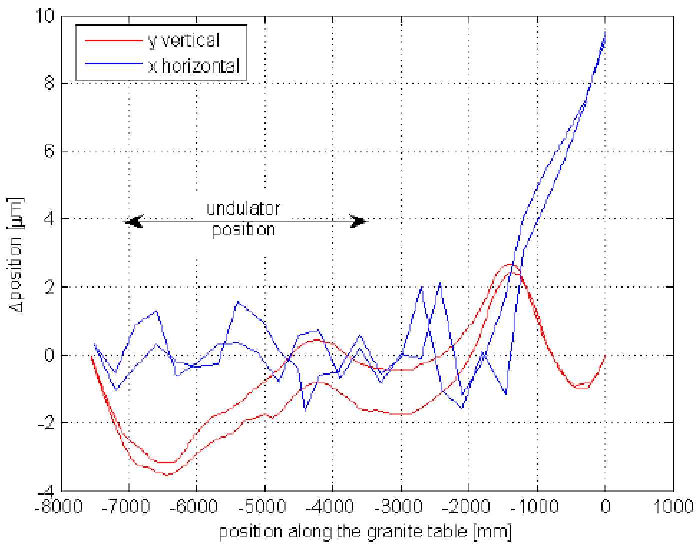
Cable Handling

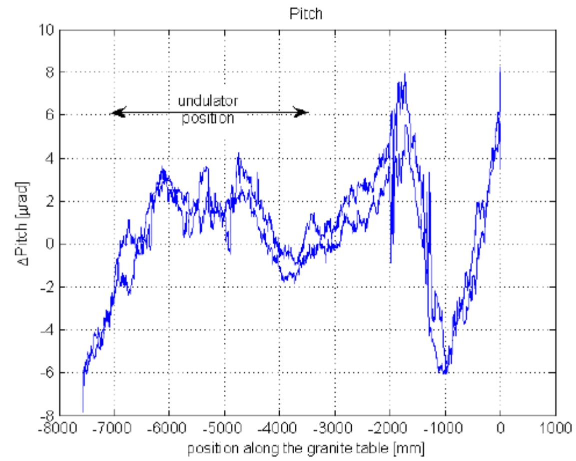
Cam Movers

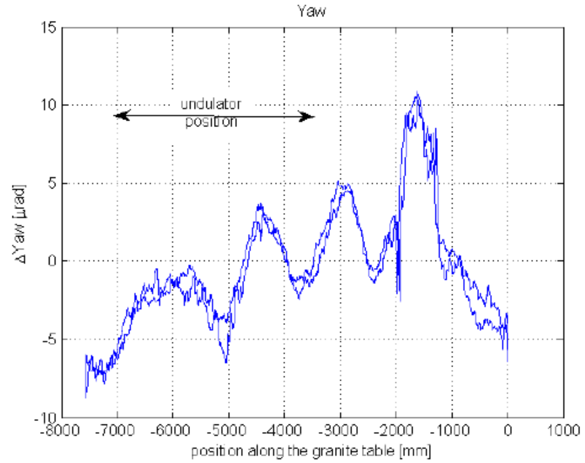
Kugler Bench

Steel Girder And Stands

Kugler Bench Performance







Measurements by Georg Gassner

X Y straightness spec: < 14 μm
Pitch and yaw spec: < 4.2 μrad

Specs met in long block region

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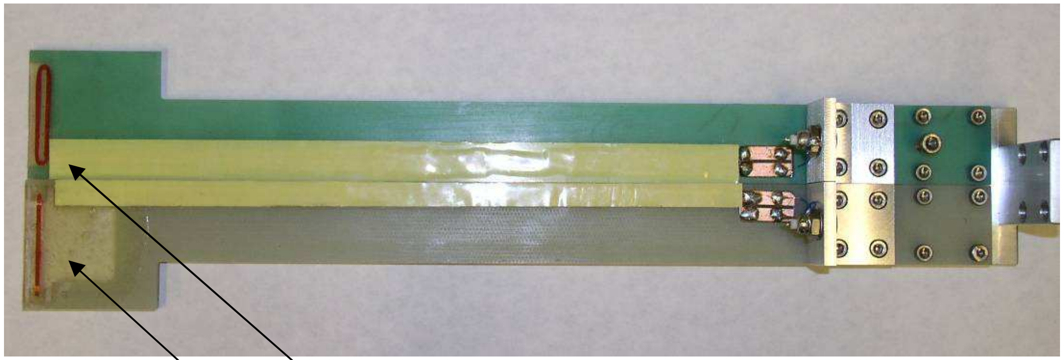
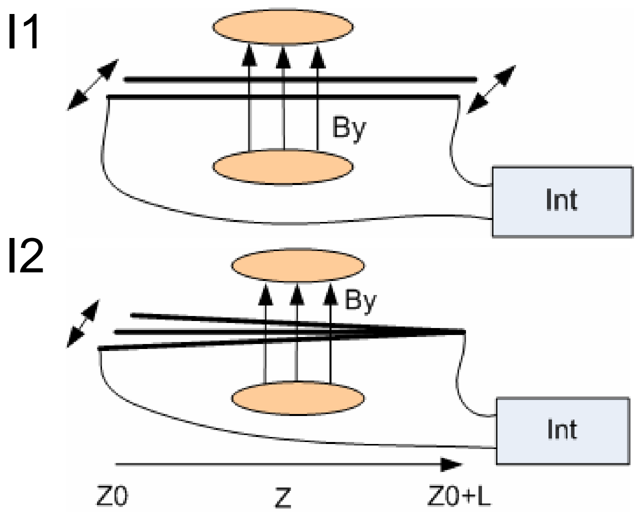
Coils For Fine Tuning Bench



Bx, By One Undulator Period Long Coils

Short Coil Zero Gauss Chamber

Field Integral Coil



Dave Jensen

Hall Probe Position Problem

Problem:

The vertical trajectories on the Dover bench and Kugler bench did not agree.

The horizontal field integrals from the Hall probe had a large y dependence. Coil measurements showed no such dependence.

We stumbled onto a paper Isaac Vasserman wrote in 1997!

The Sentron probes are sensitive to planar Hall effects after all!

ANL/APS/TB-32

Test of Horizontal Field Measurements Using Two-Axis Hall Probes at the APS Magnetic Measurement Facility

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Advanced Photon Source
Argonne National Laboratory
Argonne, IL 60439

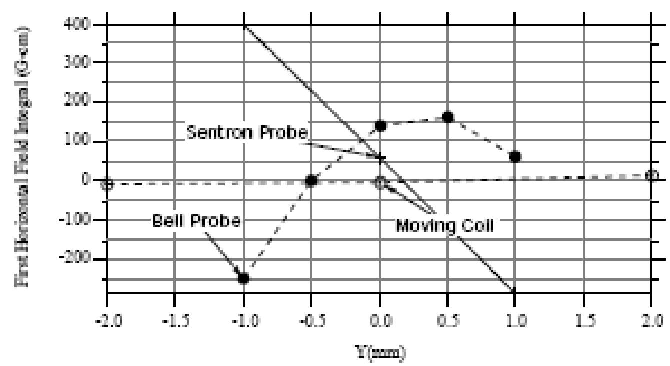
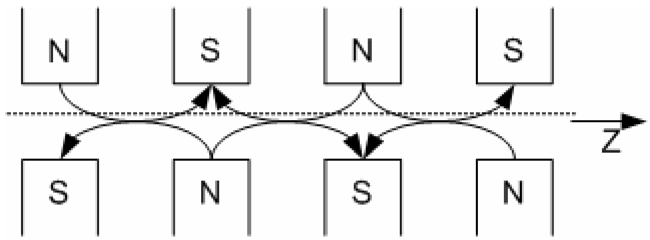
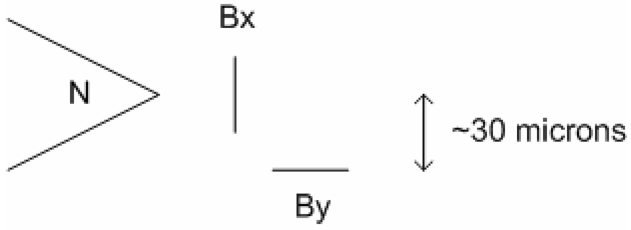


Fig. 2 Sensitivity of Bell and Sentron Hall probes to vertical position

Solution To The Hall Probe Problem



$B_z \neq 0$ Off The Midplane



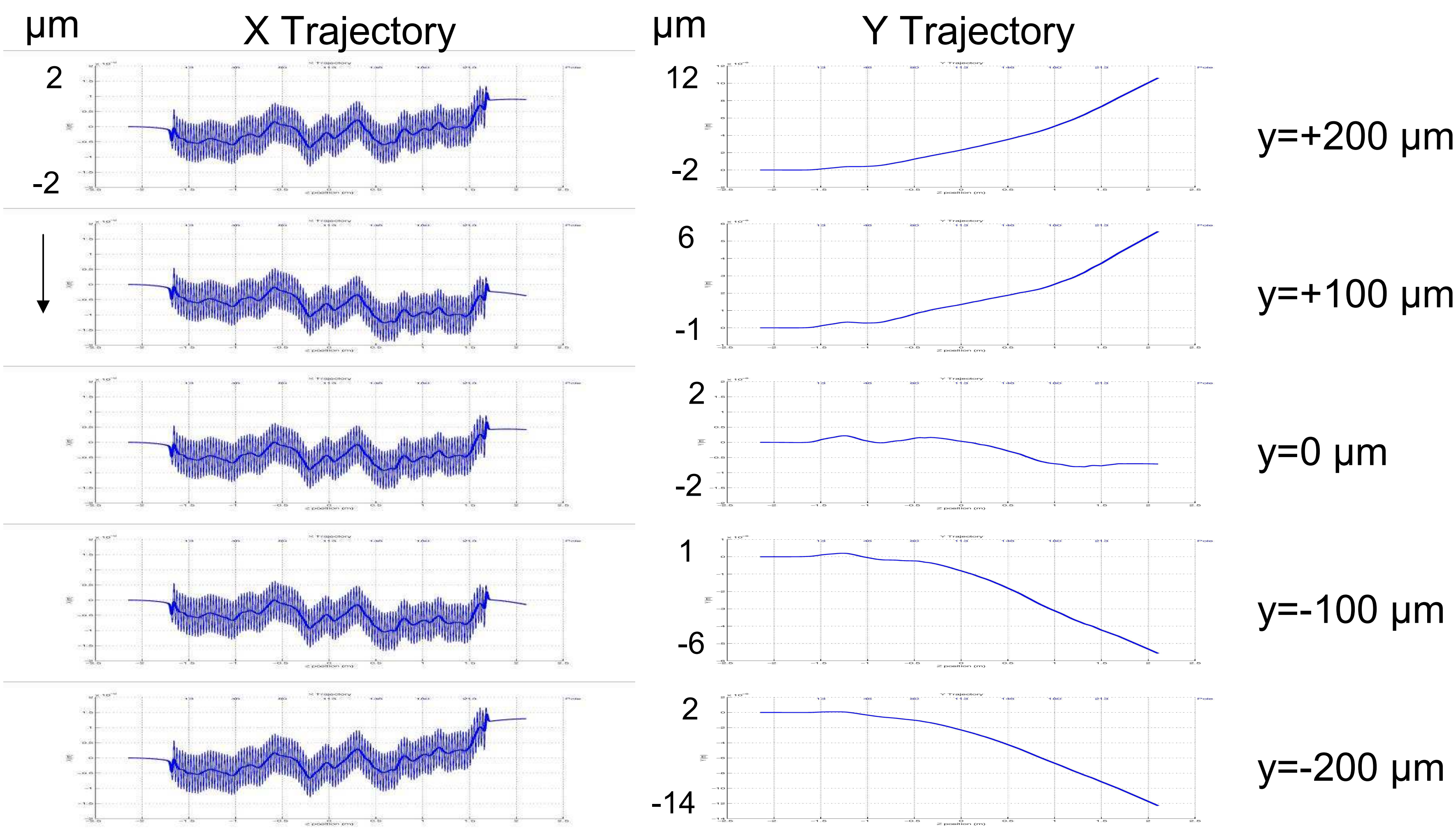
Pointed magnet gives difference in Hall probe positions.

Isaac's hypothesis:
planar Hall effect

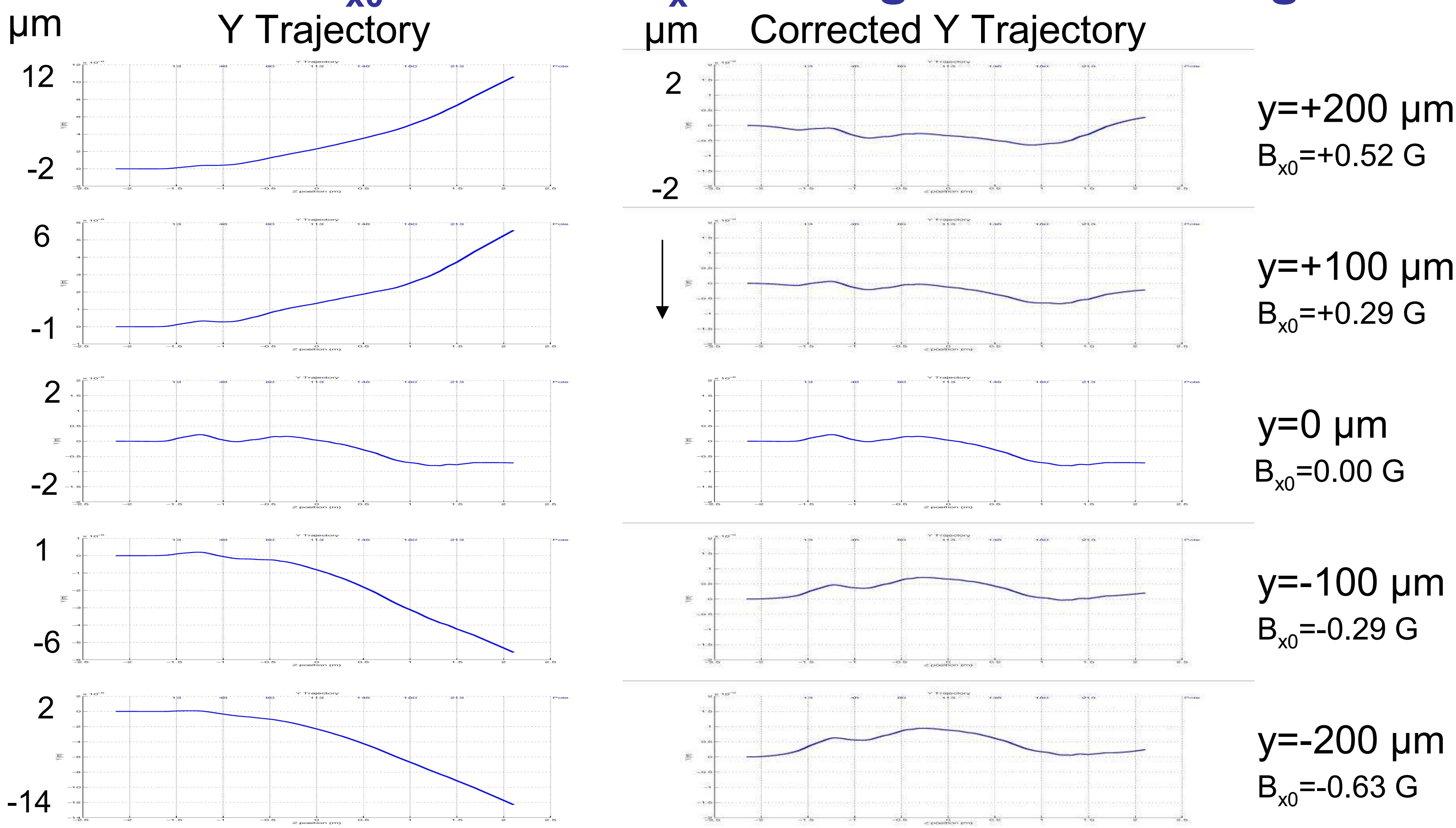
(30 microns Dover bench,
10 microns Kugler bench)

Solution:
Measure the positions of the Hall elements.
Tune the horizontal trajectory with the By probe on the midplane.
Tune the vertical trajectory with the Bx probe on the midplane.
Use only the long coil for final field integral measurements.

Effect Of Hall Probe Error On Trajectories



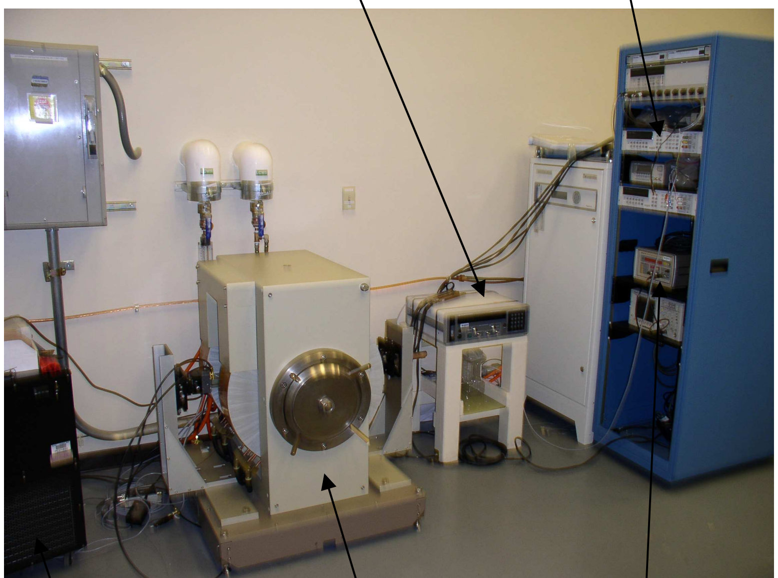
Constant B_{x0} Corrects B_x To Long Coil Field Integral



Hall Probe Calibration

Water NMR

HP3458

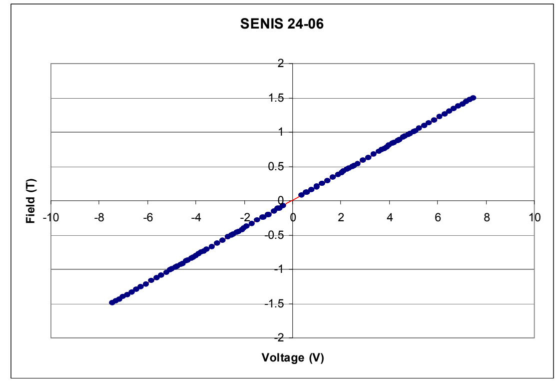


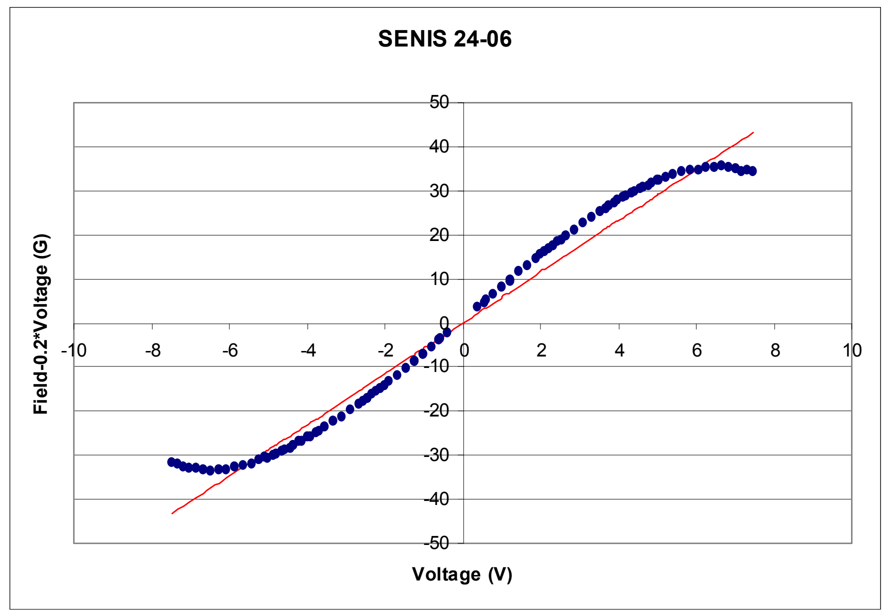
Chiller
For probe
temperature

Magnet

Metrolab
NMR

Seva Kaplounenko

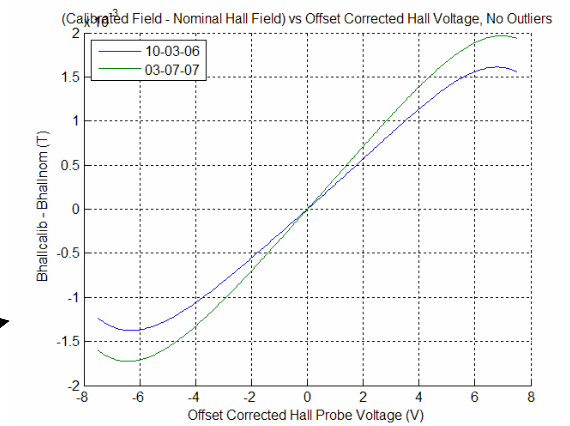




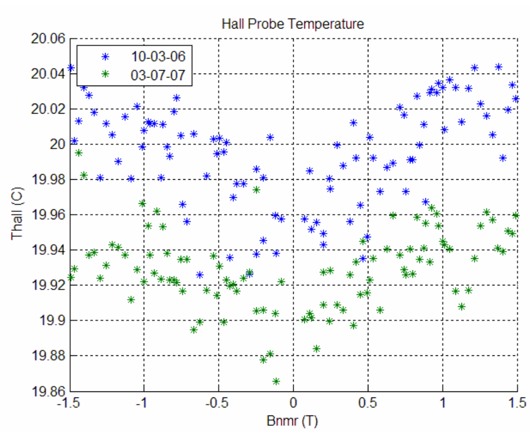
Hall Probe Calibration Problem

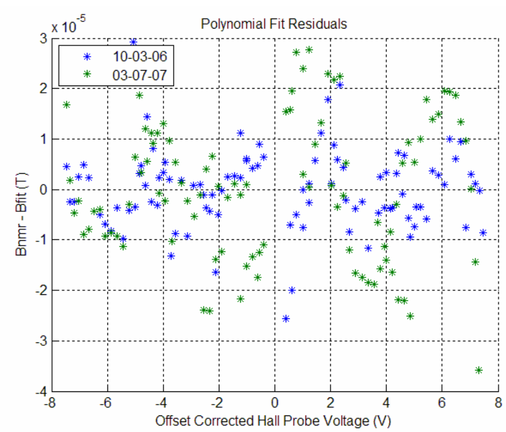
Calibration Change

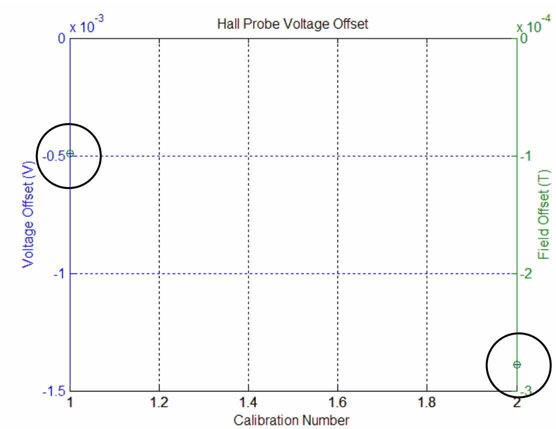
Before and after first undulator



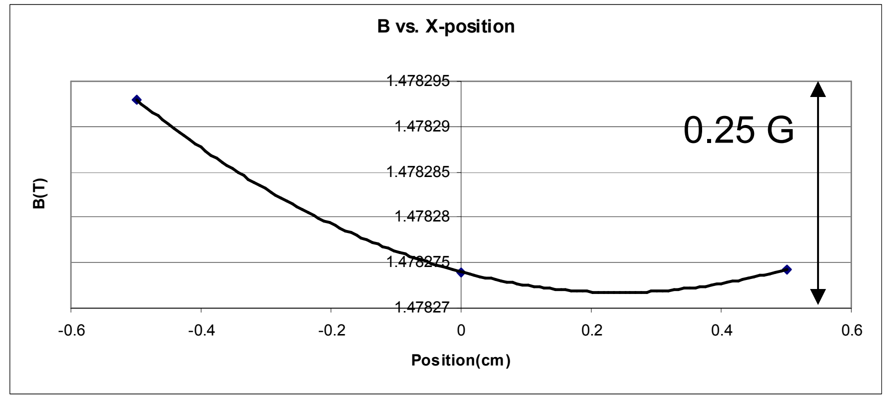
Probe temperature?
Poor fits?
Probe offset?
Calibration magnet non-uniformity?
Impurities in copper probe chiller?



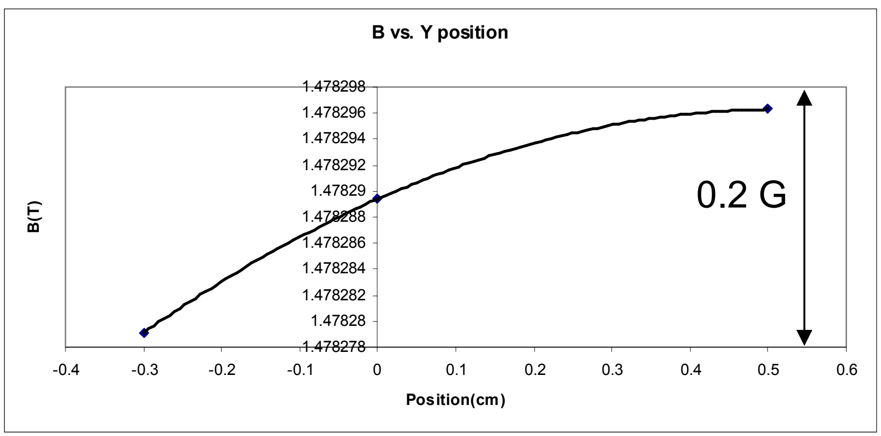


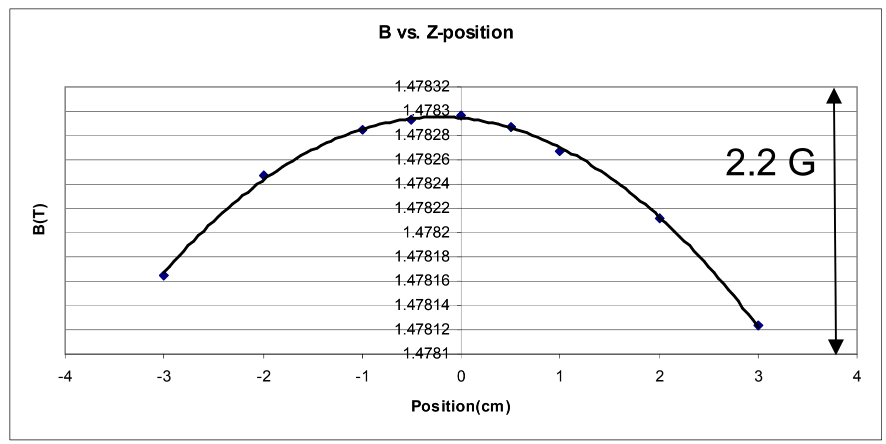


Calibration Magnet



Very uniform!





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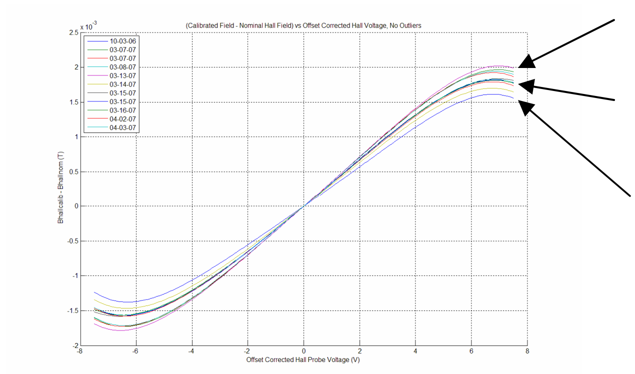
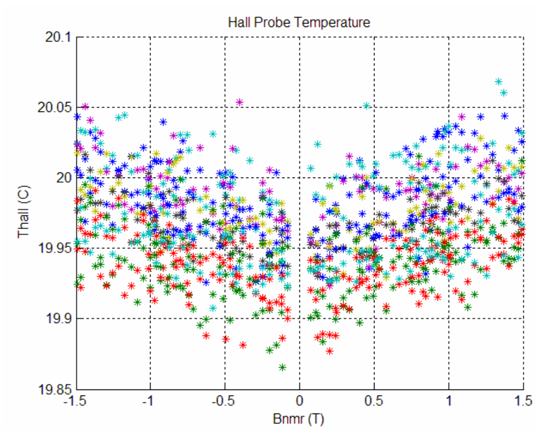
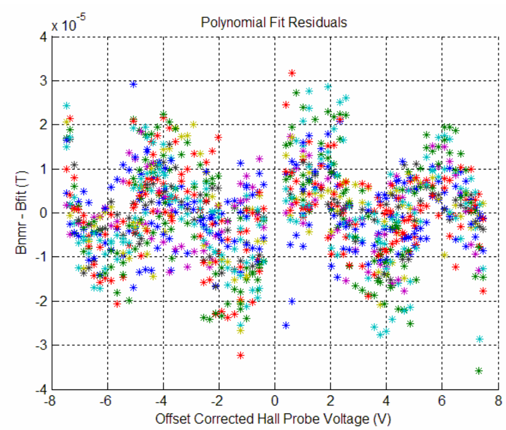
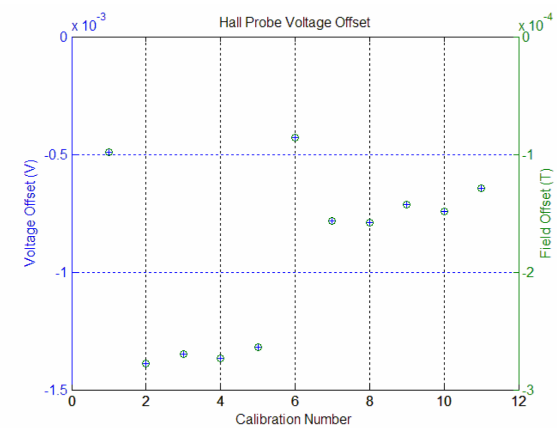
Hall Probe Calibration
Study Problem

Temperature, ok
Fits, ok
Calibration magnet uniform
Copper non-magnetic
Offsets change, why?
Stress on probe



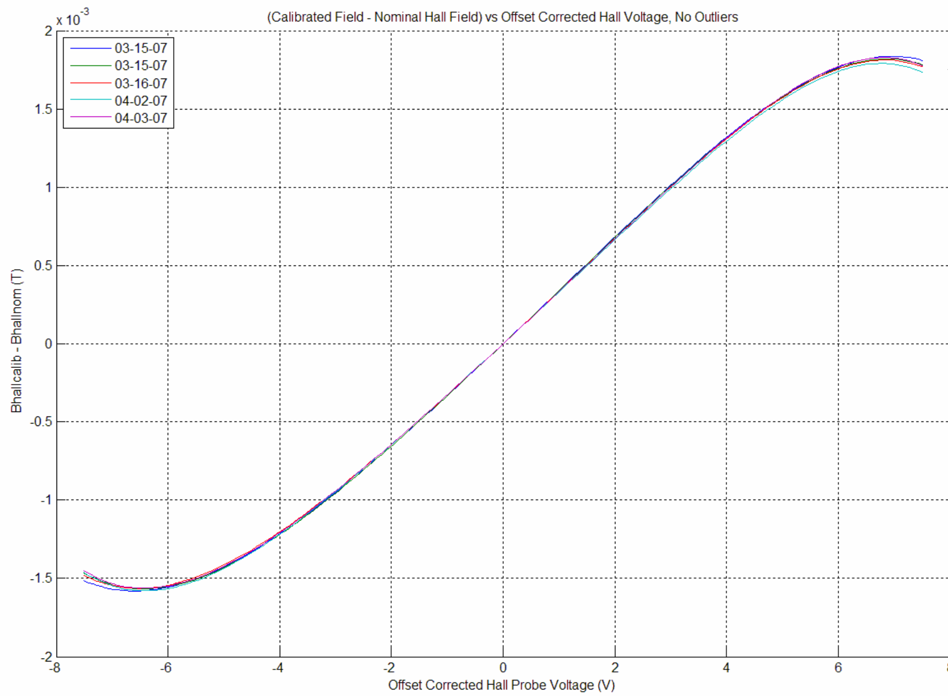




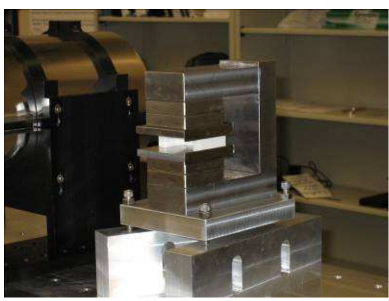


Hall Probe Calibrations In Fixed Mount

The Hall probe is calibrated in the same mount it is used in.

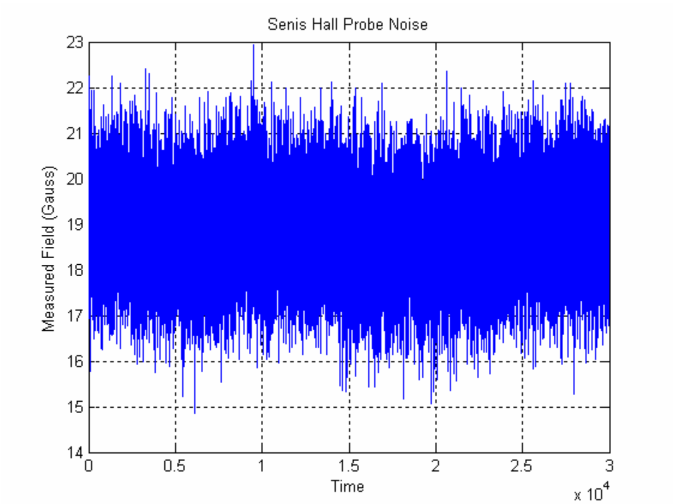


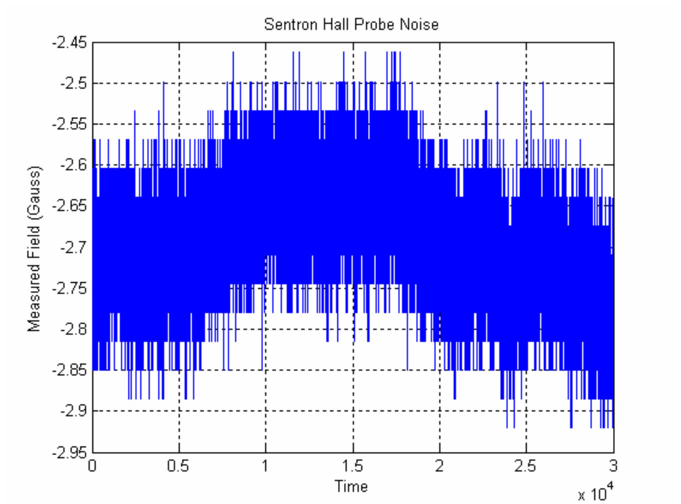
Only 03-16-07 and 04-03-07 are used so far.



Starting measurements in reference magnet before set K

Hall Probe Noise





Noise ~4 G

Noise ~0.2 G

The Senis probe did not work.
We are only using Sentron probes.
We own one Sentron probe and borrowed one from Isaac.
We are having two custom Sentron probes made for us.

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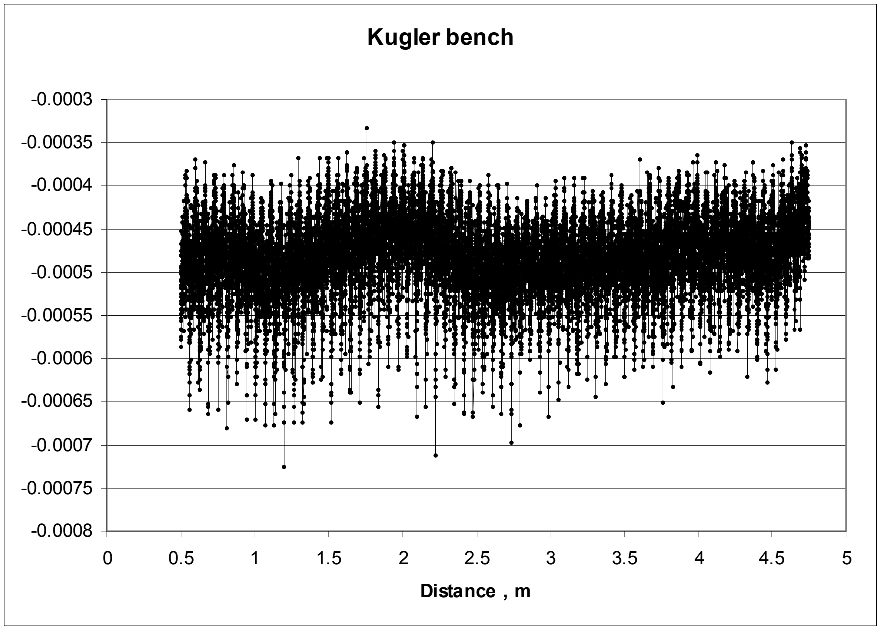
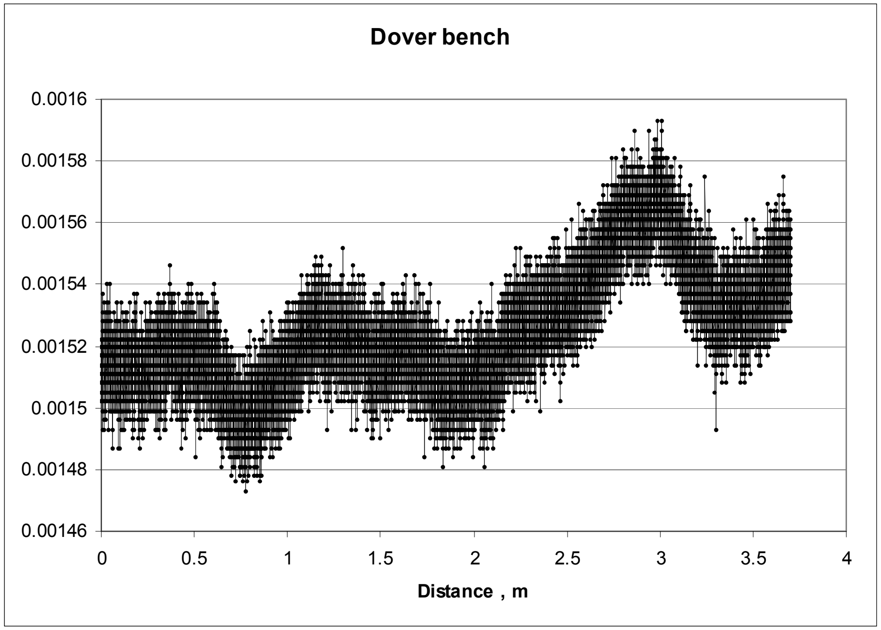
Kugler Bench Noise



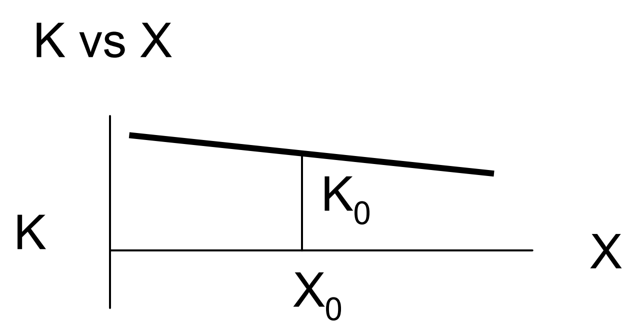


Noise ~0.2 mV

Noise ~0.03 mV

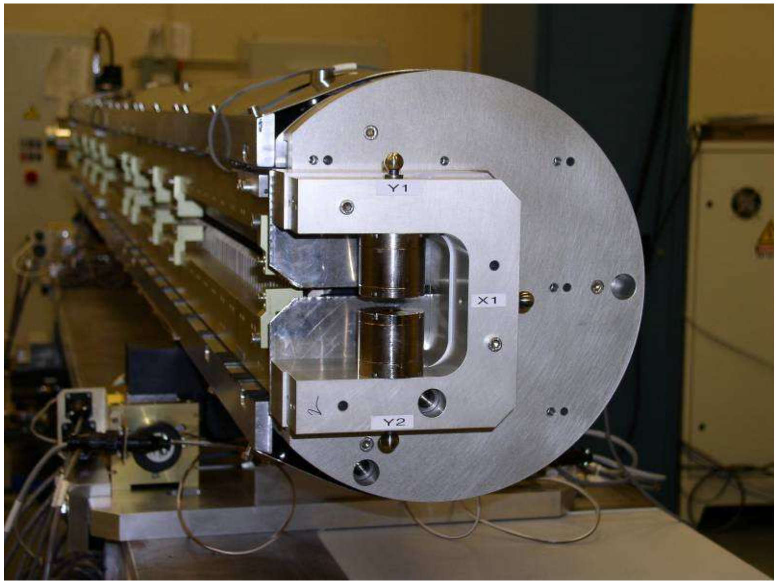
Rough tuning bench uses linear motor driver.
Fine tuning bench uses chopped motor driver.
Problem solved by adding heavy filtering to the motor lines.

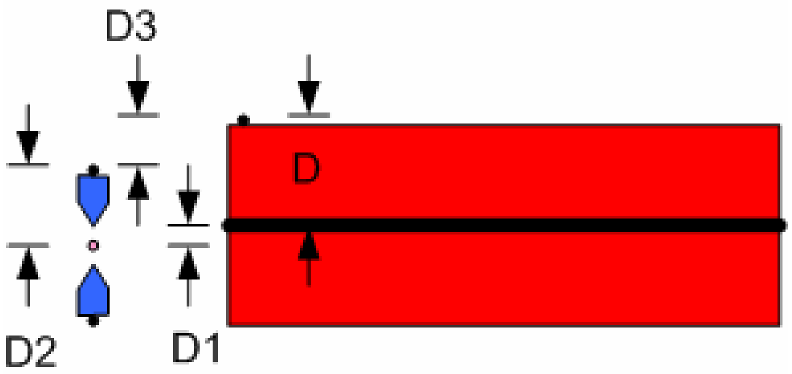
Fiducialization, Determine K vs X



Set the probe position to give the nominal K value.

Fiducialization





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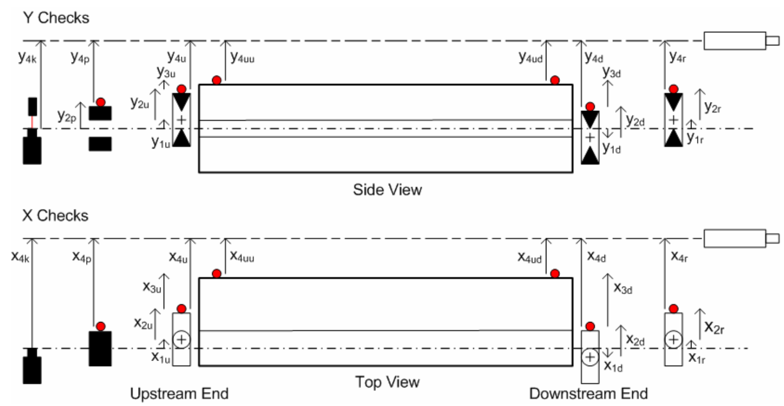
Tuning Bench Fiducialization Checks

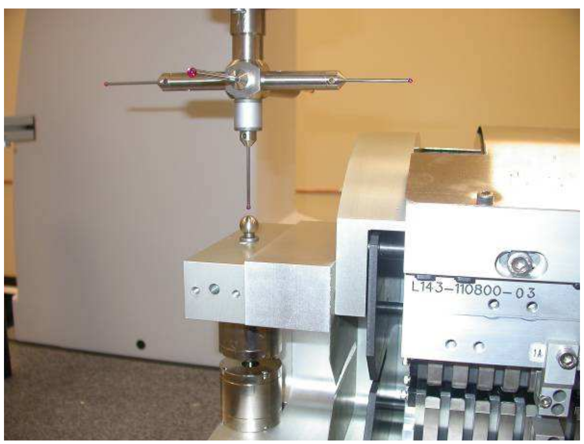
- Reference fiducialization magnets
- Optical alignment check
- Optical fiducialization check

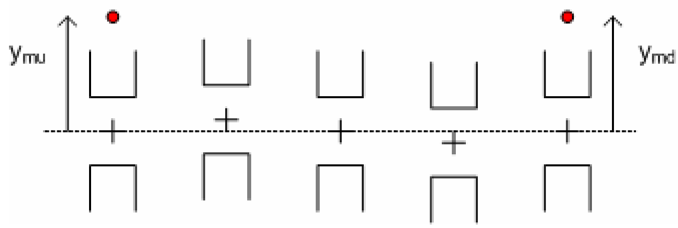


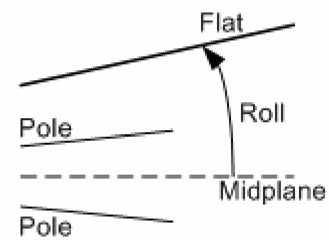
CMM Fiducialization Checks

$$y_{mu} = y_u \qquad \Delta x_{mag} = \Delta x_{mech}$$
$$y_{md} = y_d \qquad \Delta y_{mag} = \Delta y_{mech}$$

$$roll_{mu} = roll_u$$
$$roll_{md} = roll_d$$







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Conclusion

- MMF construction is complete, temperature stability and set point accuracy requirements have been met. The fine tuning bench construction met all specifications.
- The electrical noise problems are solved.
- The planar Hall effect problem is solved.
- The Hall probe calibration problem is solved. We check the Hall probe frequently in a reference magnet.
- The software is complete. We compared our software results to other programs and found no bugs.
- Mechanical alignment takes about 15 minutes.
- The field integral measurement system has been tested and is working well.
- We have a written test plan and a written fiducialization plan.
- We demonstrated a throughput of one undulator per week. Each undulator spends about 4 weeks in the MMF.
- One reference undulator gets re-measured every fourth undulator.
- We are 1/3 finished with production undulator tuning.