

LCLS-II Undulator Segment Measurement Results

SXU-003

SLAC Traveler for LCLS-II SXU Segment Measurement Results

This traveler is intended to document the checking the final magnetic measurements of an Undulator Segment performed on the Kugler bench in the Magnetic Measurement Facility (MMF) at SLAC after the completion of the tuning process. It contains basic performance indicators compared against tolerances as well as documentary information both in graphical and textual representation.

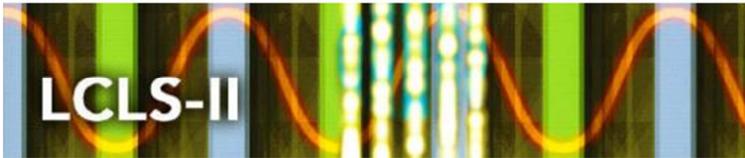
Serial number from magnet label:	29A804-003
Device name from magnet label:	SXU-003

Measurement Procedure:

The measurements have been carried out after the undulator segment had been fully tuned according to “LCLS-II Undulator Test Plan” (LCLS-TN-17-1).

Evaluation of Hall Probe Scans: Data Listings A

MATLAB function "EvaluateUndulatorField" on	11/9/2017 16:08	
A. SCAN PARAMETERS		
Serial Number	29A804-003	
Device Name	SXU-003	
z Scanning Date & Time Range	10/13/2017 16:22 - 10/16/2017 23:46	
Undulator Temperature	20.1348± 0.0036	°C
Room Temperature	20.1017± 0.0077	°C
x axis position	0.075967	m
y axis position	0.000303	m
Total number of poles per strongback	174	
Number of full field poles	168	
Number of core poles	164	
First core pole #	6	
Last core pole #	169	
Scans averaged	3	
Tuning Gap	10.000	mm
Commissioning Gap	10.451	mm



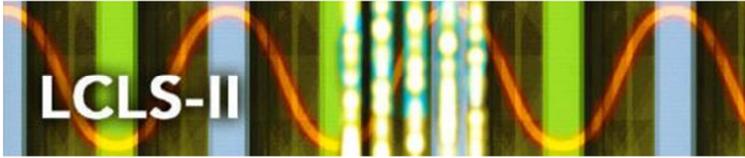
Evaluation of Hall Probe Scans at Tuning Gap: Data Listings B

MATLAB function "EvaluateUndulatorField" on	11/9/2017 16:08	
B. CORE EVALUATIONS FOR TUNING GAP		
Tuning Gap Scanning Date & Time	10/16/2017 12:44	
Tuning Temperature	20.14± 0.03	°C
Planar Hall Effect Correction Range	0.792600 - 4.098600	m
Planar Hall Effect x Corr Function	-0.40 G + (z - 0.792600 m) * 0.16 G/m	
Planar Hall Effect y Corr Function	-0.52 G + (z - 0.792600 m) * 0.34 G/m	
Coil Range	0.645650 - 4.245650	m
< λ_u >	39.003± 0.003	mm
< k_u >	161.10± 0.01	1/m
< K_u >	4.252±0.001	
< K_{eff} > @ Tuning Temperature	4.25197±0.00004	
< L_{eff} >	3.31336±0.00006	m
< $L_{2\pi}$ >	0.39157±0.00003	m
I1X (Cell Range Total)	5.28	μTm
I2X (Cell Range Total)	-32.26	μTm^2
I1Y (Cell Range Total)	-24.55	μTm
I2Y (Cell Range Total)	-43.01	μTm^2
PI (Cell Range Total)	87,019.70	T^2mm^3
Phase Shake	2.65	degXray
Cell Phase Advance (over 4.400000 m)	31,581.9 (88×360-98.1)	degXray
Undulator Entrance Phase	1029.9±0.2	degXray
Undulator Exit Phase	1032.0±0.2	degXray
Undulator Phase Imbalance: Entrance - Exit	-2.1±0.3	degXray
Cell Entrance min. Phase Shifter Correction	50.1	degXray
Cell Exit min. Phase Shifter Correction	48.0	degXray



Evaluation of Hall Probe Scans at Commissioning Gap: Data Listings C

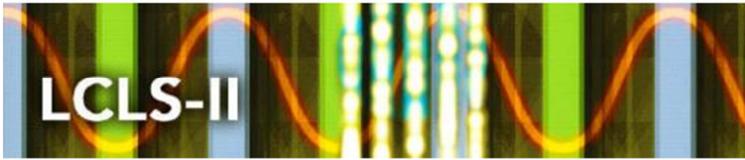
MATLAB function "EvaluateUndulatorField" on	11/9/2017 16:08	
C. CORE EVALUATIONS FOR COMMISSIONING GAP		
Tuning Gap Scanning Date & Time	10/17/2017 9:03	
Tuning Temperature	20.10± 0.03	°C
Planar Hall Effect Correction Range	0.792400 - 4.098800	m
Planar Hall Effect x Corr Function	-0.39 G + (z - 0.792400 m) * 0.17 G/m	
Planar Hall Effect y Corr Function	-0.63 G + (z - 0.792400 m) * 0.41 G/m	
Coil Range	0.645648 - 4.245648	m
<λ _u >	39.003± 0.003	mm
<k _u >	161.10± 0.01	1/m
<K _u >	4.050±0.001	
<K _{eff} > @ Tuning Temperature	4.04952±0.00004	
<L _{eff} >	3.31396±0.00006	m
<L _{2π} >	0.35880±0.00003	m
I1X (Cell Range Total)	1.64	μTm
I2X (Cell Range Total)	-42.77	μTm ²
I1Y (Cell Range Total)	-16.28	μTm
I2Y (Cell Range Total)	-32.86	μTm ²
PI (Cell Range Total)	78,944.40	T ² mm ³
Phase Shake	2.65	degXray
Cell Phase Advance (over 4.400000 m)	31,678.1 (88×360-1.9)	degXray
Undulator Entrance Phase	1078.0±0.2	degXray
Undulator Exit Phase	1080.1±0.2	degXray
Undulator Phase Imbalance: Entrance - Exit	-2.1±0.3	degXray
Cell Entrance min. Phase Shifter Correction	2.0	degXray
Cell Exit min. Phase Shifter Correction	359.9	degXray



Undulator Encoder Values: Data Listings D

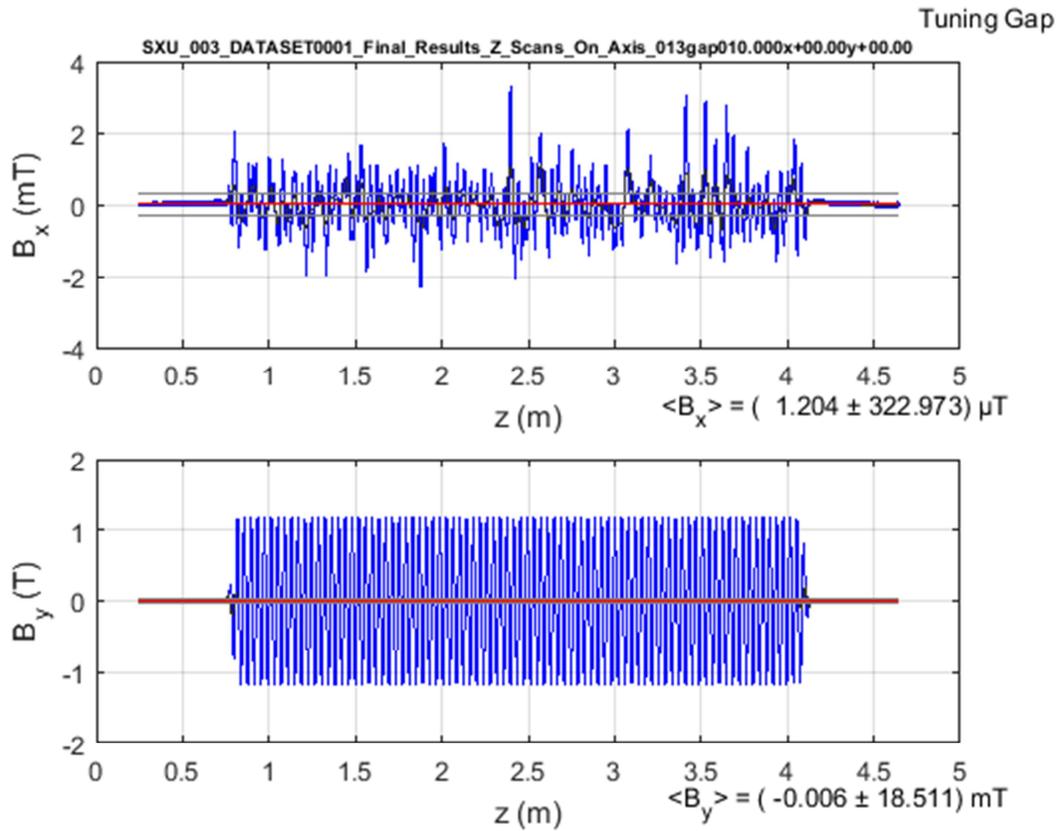
MATLAB function "EvaluateUndulatorField" on	11/9/2017 16:08	
D. ENCODER SETTINGS		
Upstream Gap Encoder Gain	-20,000.0±2.7	
Upstream Scaled Gap Encoder Offset	228.757±0.0000 mm	mm
Downstream Gap Encoder Gain	-19,999.0±6.7	
Downstream Scaled Gap Encoder Offset	228.546±0.0000 mm	mm
Upstream Scaled Top Motor Encoder Offset	271.993±0.000 mm	mm
Downstream Scaled Top Motor Encoder Offset	271.254±0.000 mm	mm

The following figures show result of the field analysis at the tuning gap.

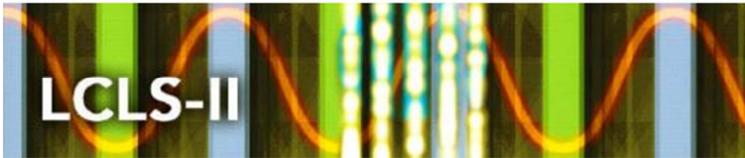


LCLS-II Undulator Segment Measurement Results

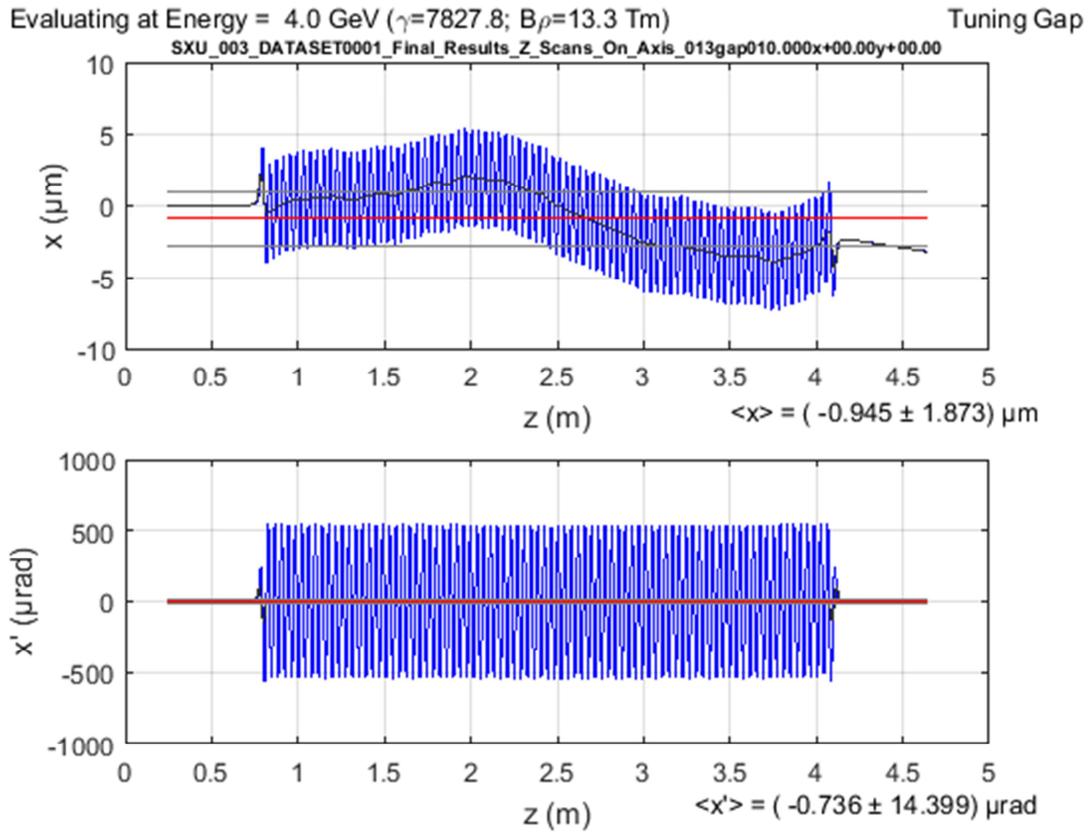
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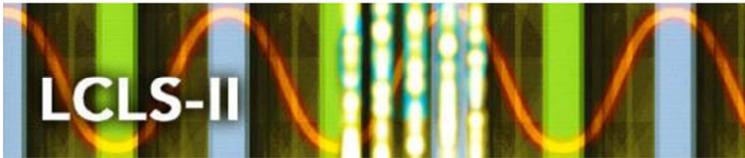
The figures show the x (upper) and y (lower) field components along the undulator tuning axis for the tuning gap. A running wiggler-period-average function is plotted in black (not very well visible in the lower figure). The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average) of that wiggler-period-average function. The corresponding mean and rms values are also printed on the right hand side underneath each figure. [Documentary Information]



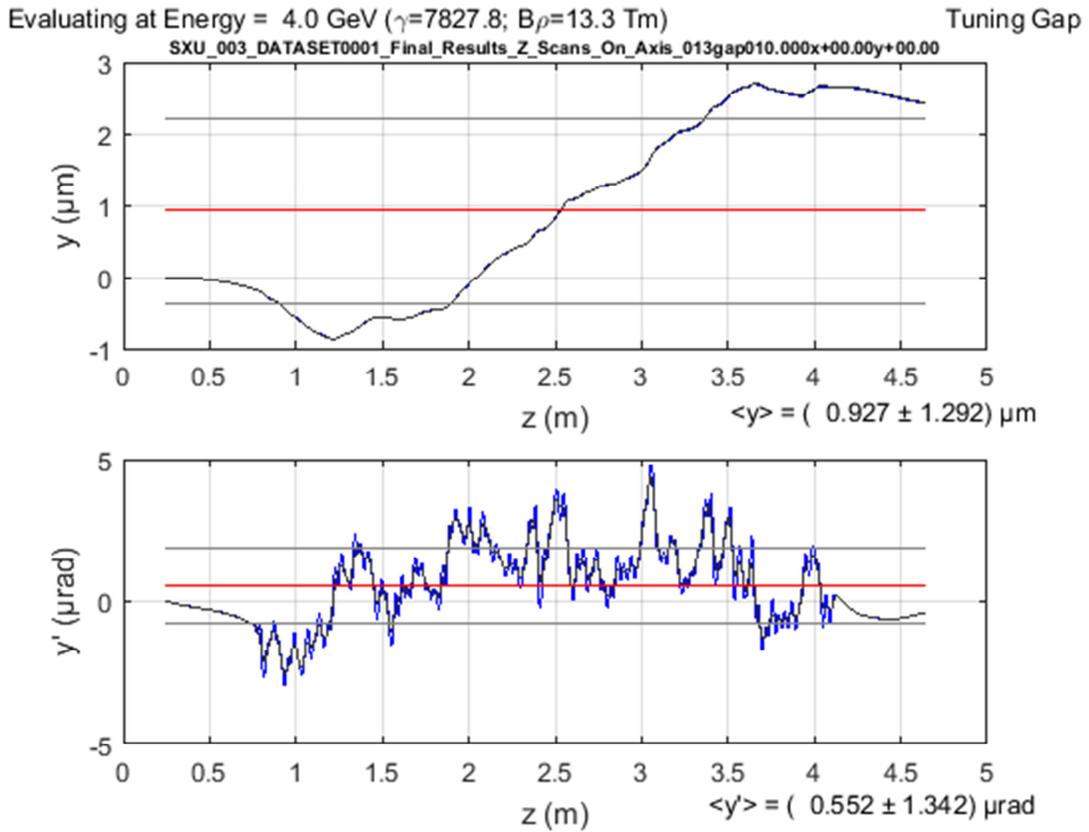
Evaluation of Hall Probe at Tuning Gap: x & x' Plot



The figures show the x (upper) and x' (lower) electron beam trajectories along the undulator tuning axis for the tuning gap based on the measured magnetic field components and estimated for an electron beam energy of 4.0 GeV. A running wiggler-period-average function is plotted in black (difficult to see in the lower figure). The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average) of that wiggler-period-average function. The corresponding mean and rms values are also printed on the right hand side underneath each figure. [Documentary Information]



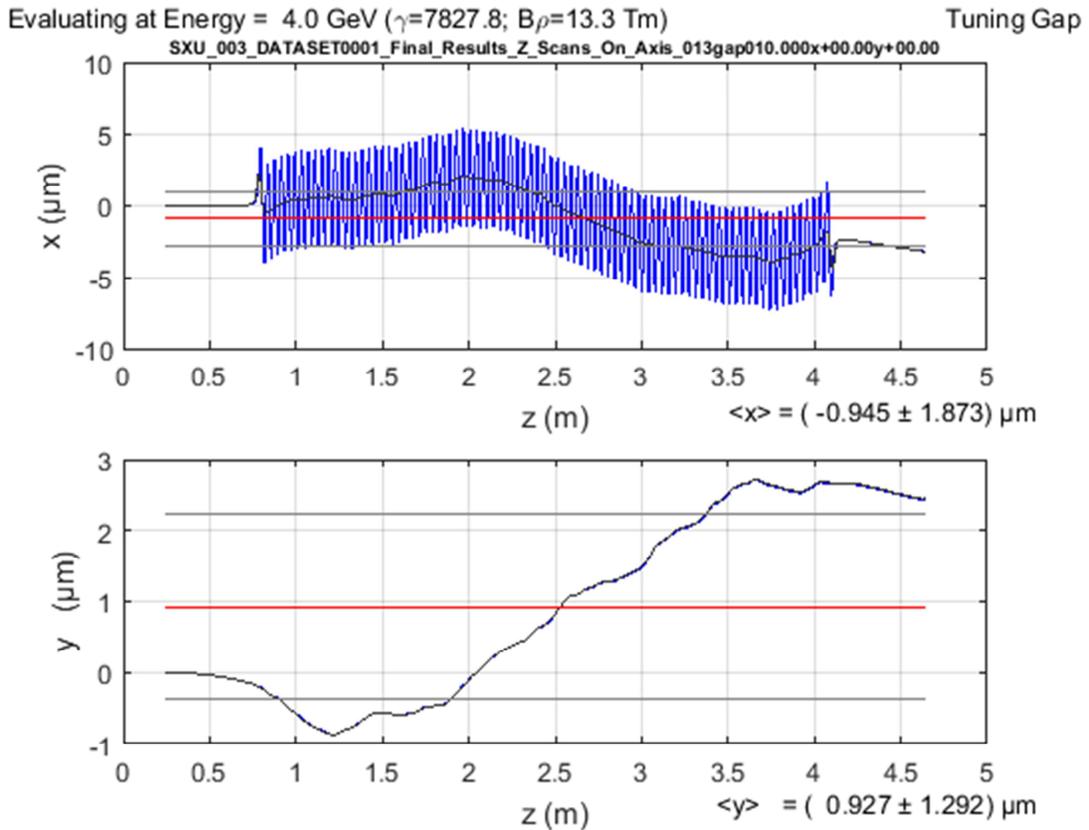
Evaluation of Hall Probe Scans at Tuning Gap: y & y' Plot



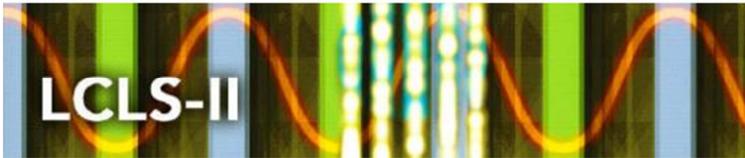
The figures show the y (upper) and y' (lower) electron beam trajectories along the undulator tuning axis for the tuning gap based on the measured magnetic field components and estimated for an electron beam energy of 4.0 GeV. A running wiggler-period-average function is plotted in black (difficult to see). The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average) of that wiggler-period-average function. The corresponding mean and rms values are also printed on the right hand side underneath each figure. [Documentary Information]



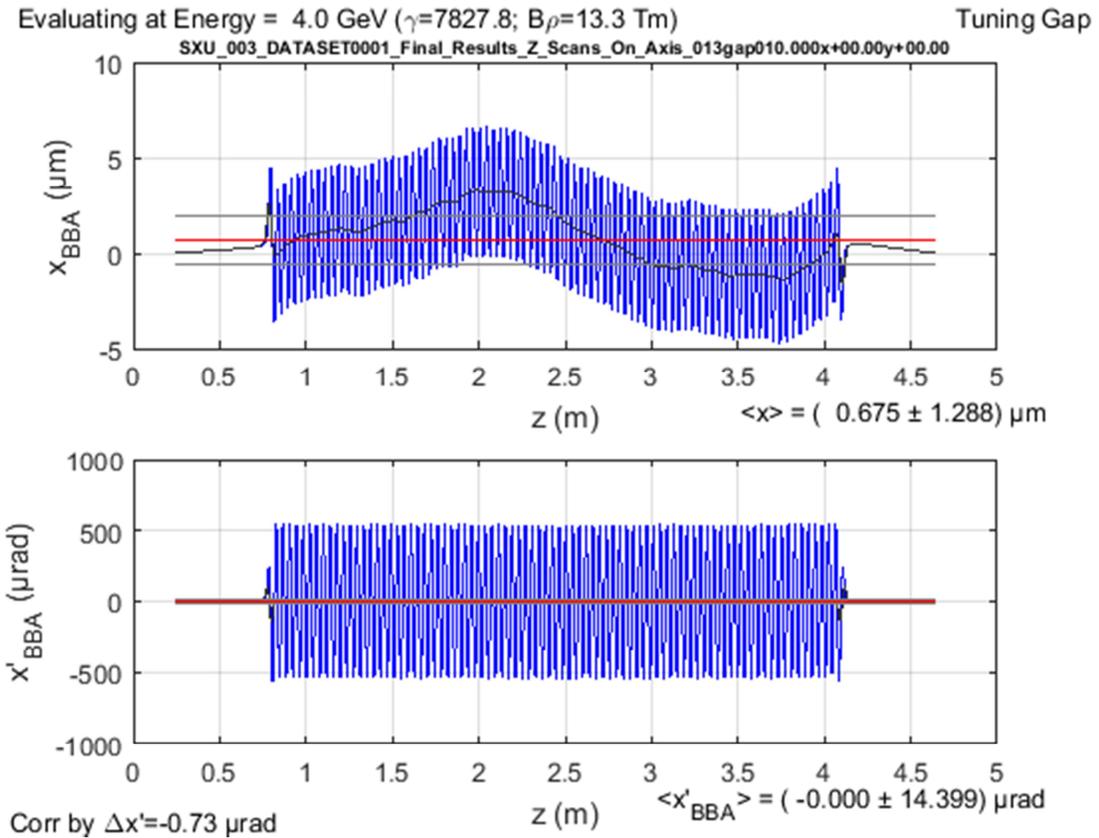
Evaluation of Hall Probe Scans at Tuning Gap: x & y Plot



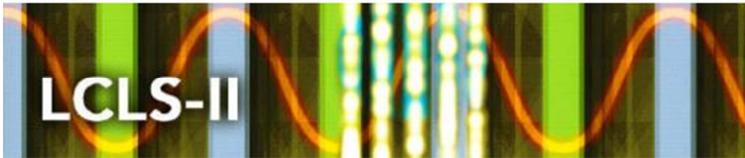
The figures show the x (upper) and y (lower) electron beam trajectories along the undulator tuning axis for the tuning gap based on the measured magnetic field components and estimated for an electron beam energy of 4.0 GeV. A running wiggler-period-average function is plotted in black (identical with the trajectory in the lower figure). The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average) of that wiggler-period-average function. The corresponding mean and rms values are also printed on the right hand side underneath each figure. [Documentary Information]



Evaluation of Hall Probe plus BBA correction at Tuning Gap: x & x' Plot



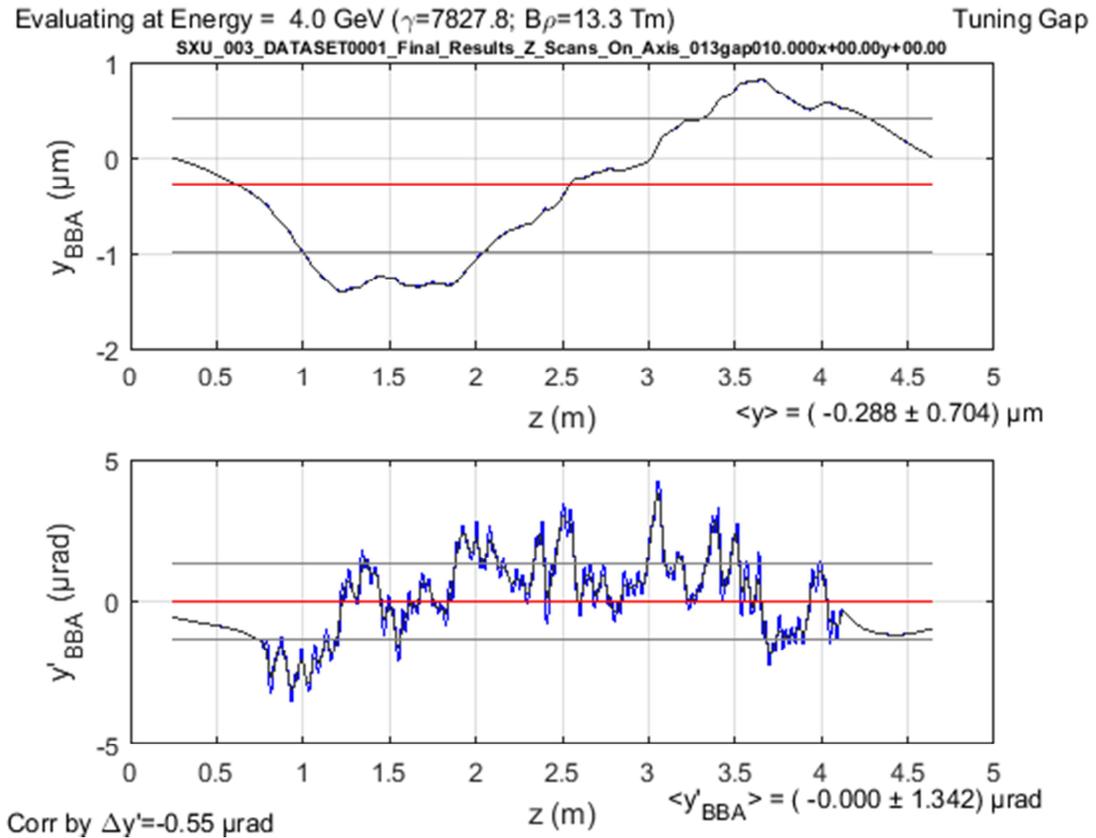
The figures show the x (upper) and x' (lower) electron beam trajectories along the undulator tuning axis for the tuning gap based on the measured magnetic field components after BBA correction (to zero the amplitudes at the cell boundaries) and estimated for an electron beam energy of 4.0 GeV. A running wiggler-period-average function is plotted in black (difficult to see in the lower figure). The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average) of that wiggler-period-average function. The corresponding mean and rms values are also printed on the right hand side underneath each figure. The amount of BBA correction applied is printed underneath the lower left corner of the lower figure. [Documentary Information]



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Evaluation of Hall Probe plus BBA correction at Tuning Gap: y & y' Plot



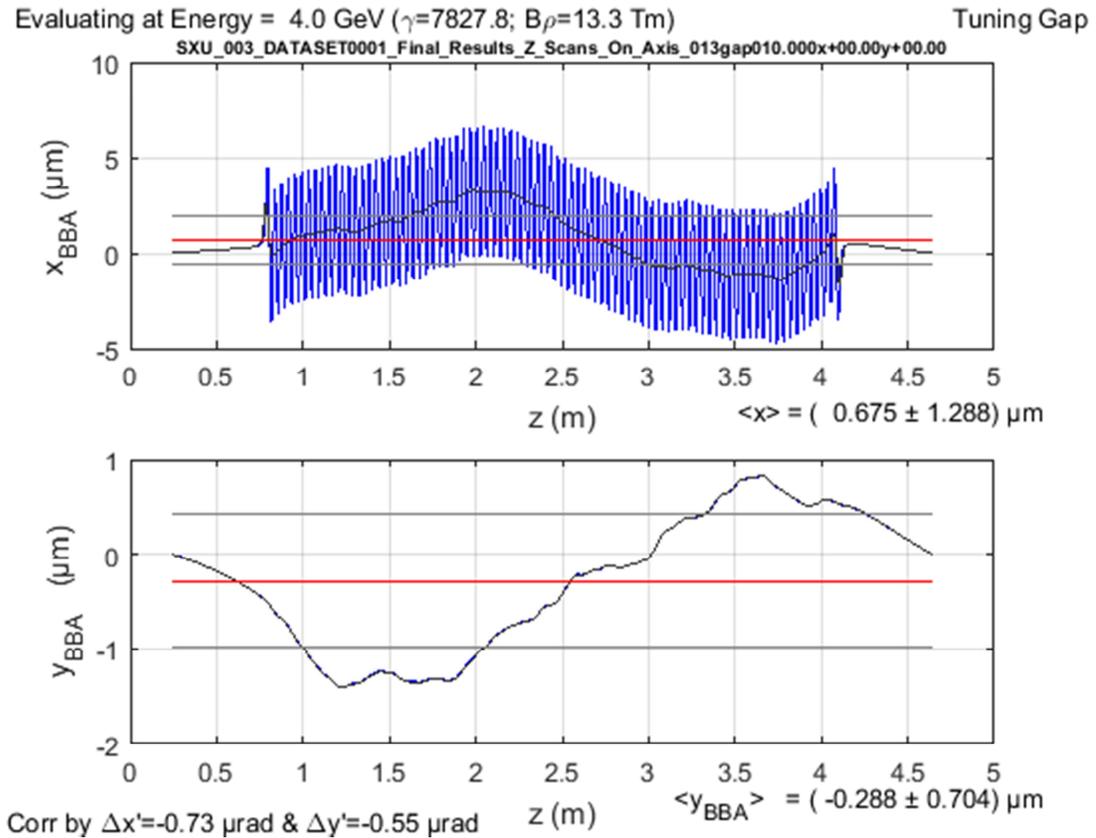
The figures show the y (upper) and y' (lower) electron beam trajectories along the undulator tuning axis for the tuning gap based on the measured magnetic field components after BBA correction (to zero the amplitudes at the cell boundaries) and estimated for an electron beam energy of 4.0 GeV. A running wiggler-period-average function is plotted in black (identical with the trajectories). The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average) of that wiggler-period-average function. The corresponding mean and rms values are also printed on the right hand side underneath each figure. The amount of BBA correction applied is printed underneath the lower left corner of the lower figure. [Documentary Information]



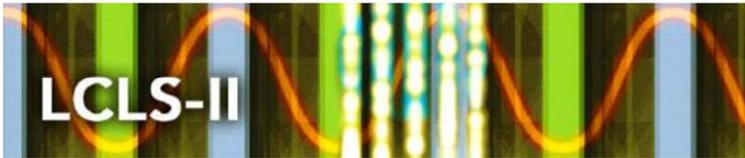
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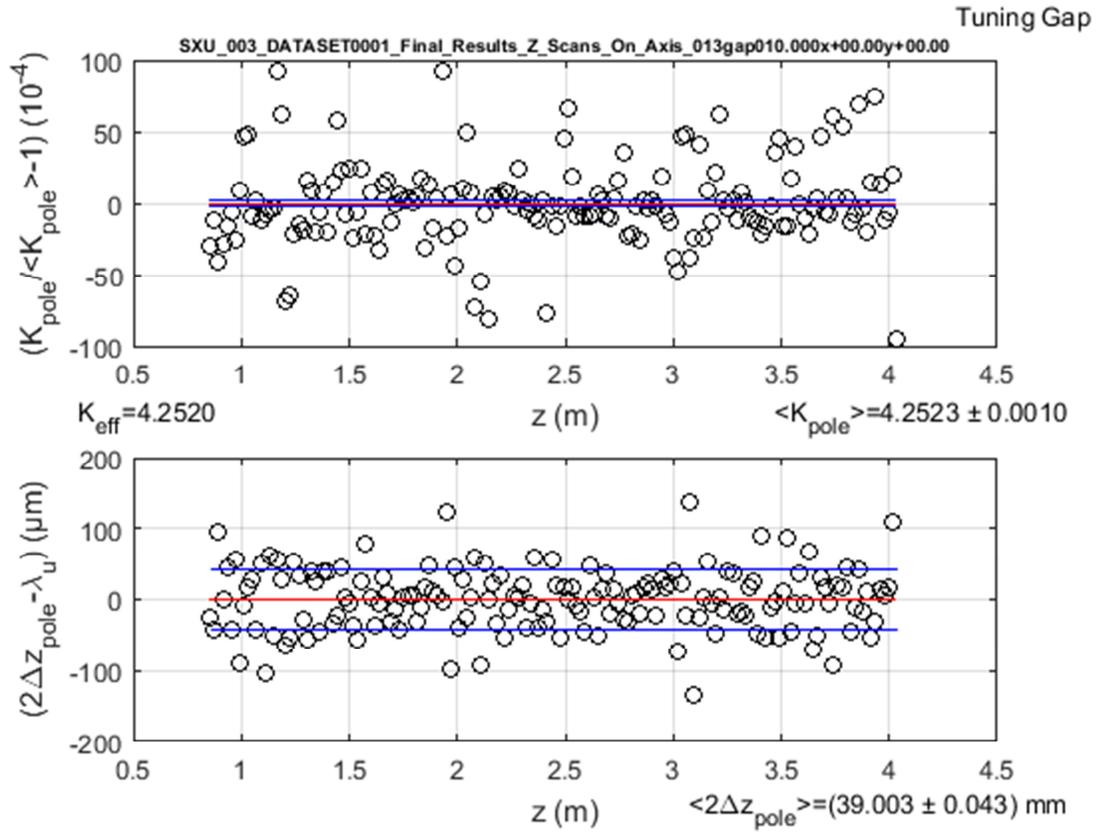
Evaluation of Hall Probe plus BBA correction at Tuning Gap: x & y Plot



The figures show the x (upper) and y (lower) electron beam trajectories along the undulator tuning axis for the tuning gap based on the measured magnetic field components after BBA correction (to zero the amplitudes at the cell boundaries) and estimated for an electron beam energy of 4.0 GeV. A running wiggler-period-average function is plotted in black (identical with the trajectory in the lower figure). The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average) of that wiggler-period-average function. The corresponding mean and rms values are also printed on the right hand side underneath each figure. The amount of BBA correction applied is printed underneath the lower left corner of the lower figure. [Documentary Information]

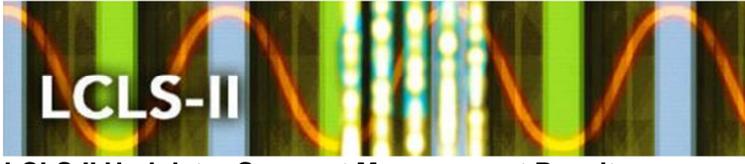


Evaluation of Hall Probe at Tuning Gap: K and λ_u variations



The figures show the per-pole undulator strength K_{pole} (upper) and the deviation of the pole width from the expected value of $\lambda_u/2$ (lower) for the 164 core undulator poles for the tuning gap. The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two black lines above and below the average). The corresponding mean and rms values are also printed on the right hand side underneath each figure. [Documentary Information]

For description of K calculation see next page.



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K calculation description for previous page:

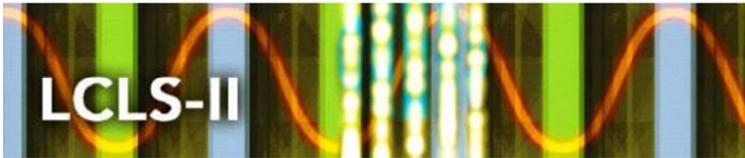
The undulator parameter, K_{pole} , in the upper figure, is calculated for each of the core poles based on the scanned vertical field values $B_y(z)$ as well as an interpolation of the upstream, $z_{0-dn,pole}$, and downstream, $z_{0-up,pole}$, field zero crossing locations using the following formula:

$$K_{pole}(z_{pole}) = \frac{\Delta z_{pole}}{2\pi} \frac{e}{m_e c} \sqrt{\frac{2}{\Delta z_{pole}} \int_{z_{0-up,pole}}^{z_{0-dn,pole}} B_y^2(\hat{z}) d\hat{z}}$$

The term $\frac{e}{m_e c}$ uses the electron mass, m_e , the speed of light, c , and the electron's electric charge, e . The variable Δz_{pole} stands for

$$\Delta z_{pole} = z_{0-dn,pole} - z_{0-up,pole}$$

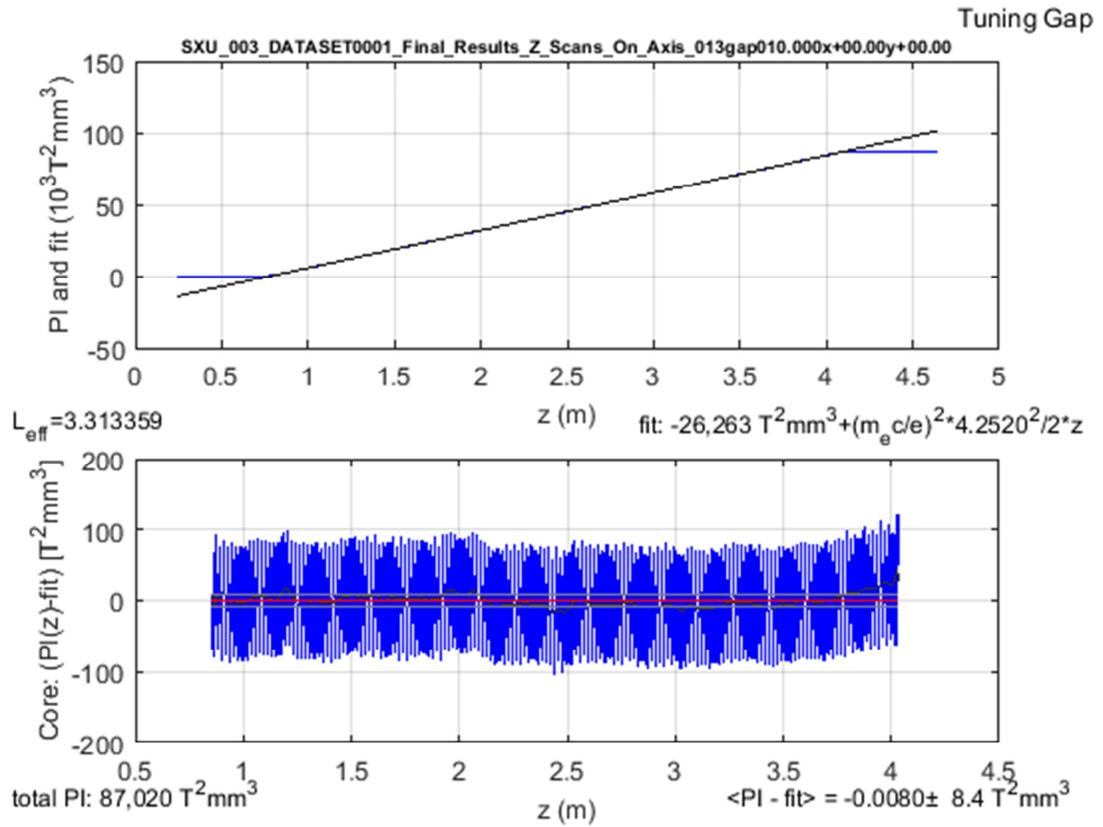
$$z_{pole} \approx \frac{1}{2} (z_{0-dn,pole} + z_{0-up,pole})$$



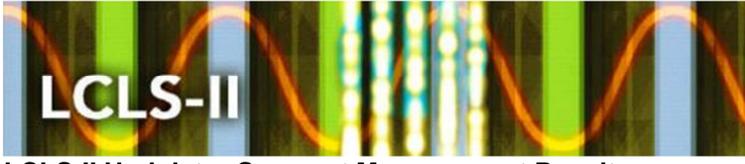
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Evaluation of Hall Probe Scans for Tuning Gap: Phase Integral Plot



A description of the figure is given on the next page:



LCLS-II Undulator Segment Measurement Results

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Figure description for previous page:

The upper figure shows the phase integral of an electron calculated from the measured on-axis magnetic field components for the tuning gap:

$$PI(z) = \int_0^z BL_{x1}^2(\hat{z}) d\hat{z} + \int_0^z BL_{y1}^2(\hat{z}) d\hat{z}$$

with

$$BL_{x1,y1}(z) = \int_0^z B_{x,y}(\hat{z}) d\hat{z} - \frac{1}{L} \int_0^L \left\{ \int_0^{\hat{z}} B_{x,y}(\hat{z}) d\hat{z} \right\} d\hat{z}$$

The function

$$\bar{PI}(z) = \bar{PI}(0) + z \left(\frac{m c}{e} \right)^2 \frac{1}{2} K_{eff}^2,$$

fitted to the measured phase integral $PI(z)$ with fit coefficients $\left(\frac{m c}{e} \right)^2 \frac{1}{2} K_{eff}^2$ and, can be seen as a straight black line in the upper plot. The values of the fit coefficients are printed at the right hand side underneath the upper figure. On the lower left of the upper figure the effective undulator length is printed, which is obtained as the distance over the undulator core, where the blue and black lines in the plot are on top of each other: $L_{eff} = PI(z_{max}) / \left(\frac{d\bar{PI}(z)}{dz} \right)$.

The lower figure shows the residuals between the phase integral and the fit function over the core part of the undulator magnet. A running wiggler-period-averaged function is plotted in black. The horizontal lines indicate the mean (center red line) and the rms deviations from the mean (two blue lines above and below the mean) of that wiggler-period-averaged function. The corresponding mean and rms values are also printed on the right hand side underneath the figure. On the lower left of the plot, the total phase integral accumulated along the undulator magnet, is shown, i.e., $PI(z_{max})$, the right-hand side value of the blue line in the upper plot.

The wiggler period averaged phase deviation, $\langle \Delta\phi \rangle_{\lambda_u}(z)$ can be calculated from $PI(z)$ via

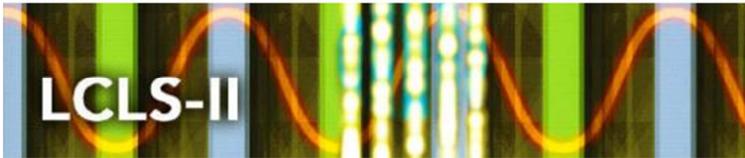
$$\langle \Delta\phi \rangle_{\lambda_u}(z) = \frac{2\pi}{L_{2\pi}} \left(\frac{e}{m c} \right)^2 \int_{z - \frac{\lambda_u}{2}}^{z + \frac{\lambda_u}{2}} (PI(\hat{z}) - \bar{PI}(\hat{z})) d\hat{z},$$

integrated over the undulator core.

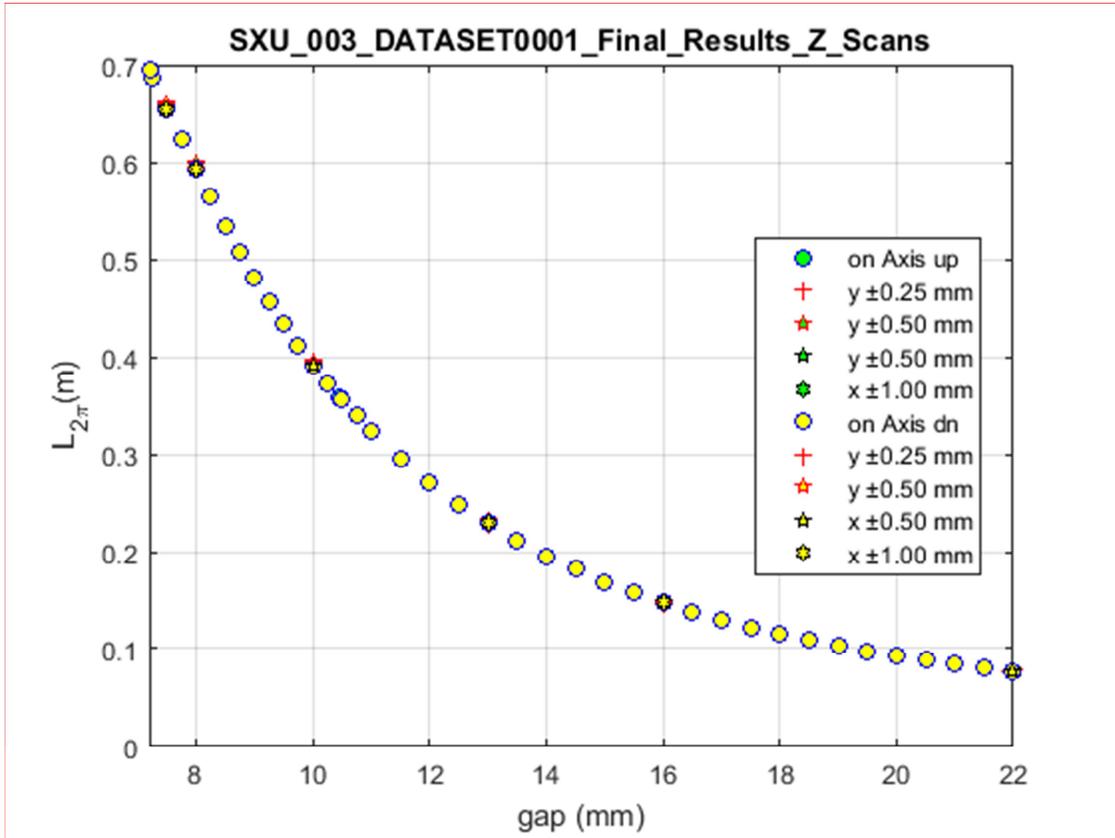
Here $L_{2\pi} = \lambda_u \left(1 + \frac{1}{2} K_{eff}^2 \right)$ (see next figure) is the free space distance over which a phase slippage of 2π occurs. The phase shake, $(\langle \Delta\phi \rangle)_{rms}$, which will be discussed later in this document is calculated as

$$(\langle \Delta\phi \rangle_{\lambda_u})_{rms} = (\langle \phi \rangle_{\lambda_u}(z) - \langle \langle \phi \rangle_{\lambda_u}(z) \rangle)_{rms}$$

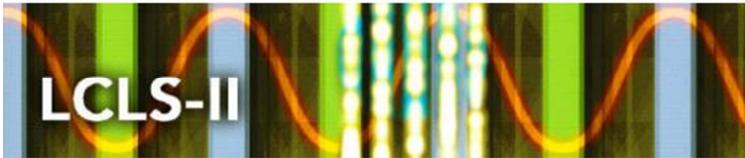
The following figures show the results of the gap dependent analysis.



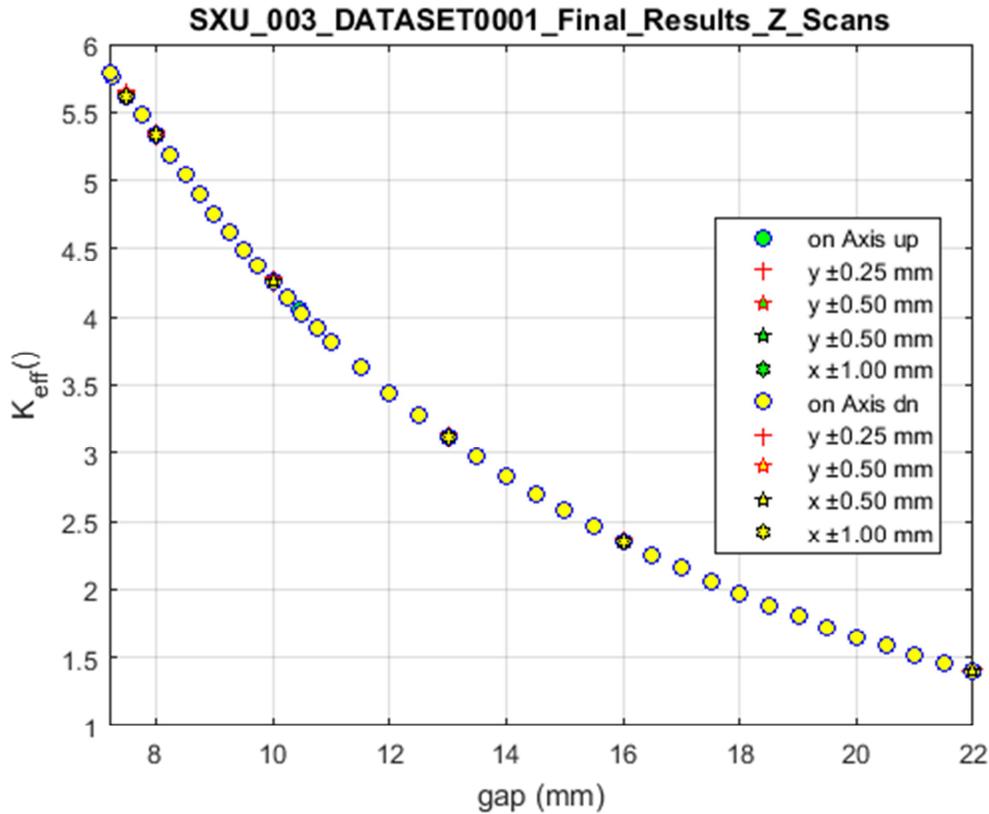
Evaluation of Hall Scans: $L_{2\pi}$ vs gap



The figure shows the free space distance over which a 2π slippage occurs between the radiation field and the electron bunch (see explanation above) as a function of undulator gap over the operational gap range. Note: the free space travel distance required to accumulate 2π slippage gets shorter towards larger gap values, which correspond to shorter undulator wavelengths. [Documentary Information]

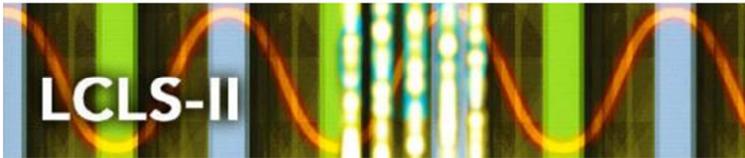


Evaluation of Hall Scans: K_{eff} vs gap

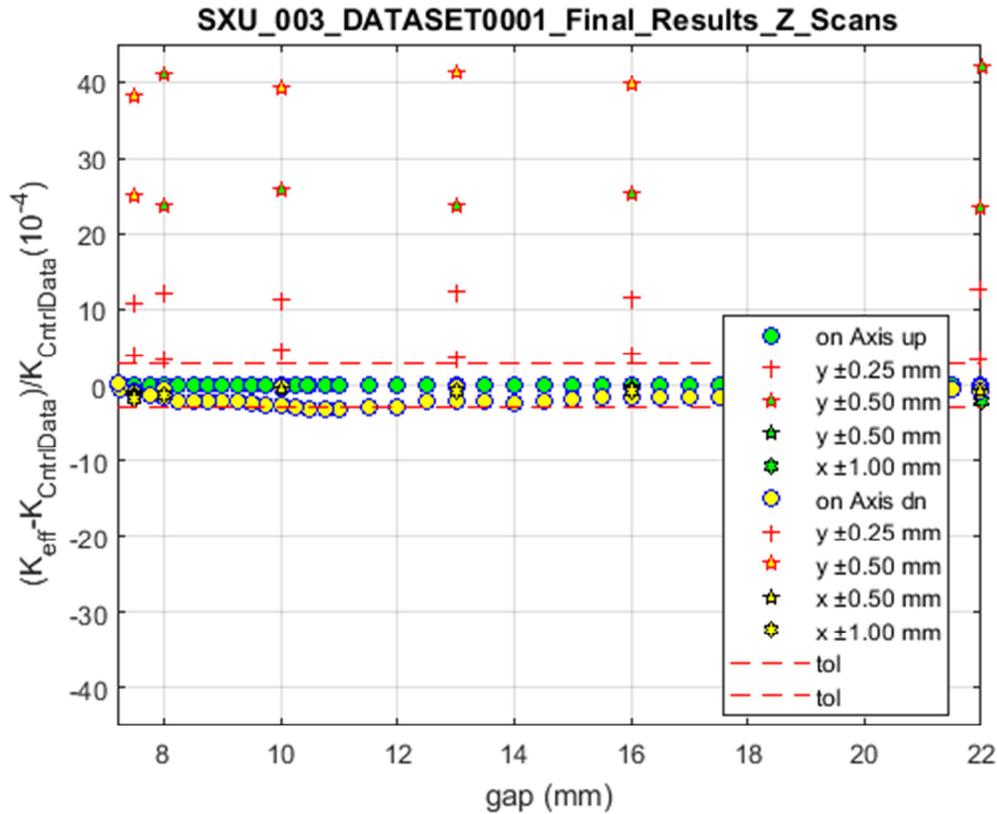


The figure shows undulator strength K_{eff} as a function of gap over the 7.2 mm – 22 mm operational range. The legend shows a number of different cases that will be explained later in this document because their effect cannot be observed in this full scale plot. Note: The gap values are derived from the readings of the two gap encoders installed on the SXU. In that sense these are nominal gap numbers that will be close but not identical to each of the individual pole separations measured across the undulator gap.

The continuous conversion between the two axes (i.e. $K_{eff}(gap)$ and $gap(K_{eff})$) will be done during operations based on the list of reference data points stored in file `sxu_003_k_vs_gap_spline.dat` in the Controls Data folder on the V: drive (see final section of this document for file information). From that list $K_{eff}(gap)$ and $gap(K_{eff})$ can be calculated via cubic spline fits or equivalent. [Documentary Information]

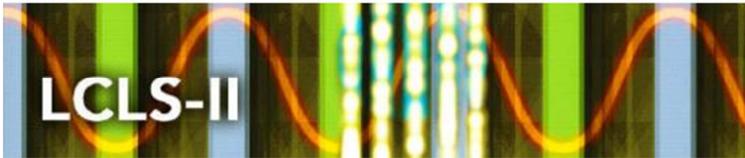


Evaluation of Hall Scans: $K_{eff} - K_{control}$ vs gap

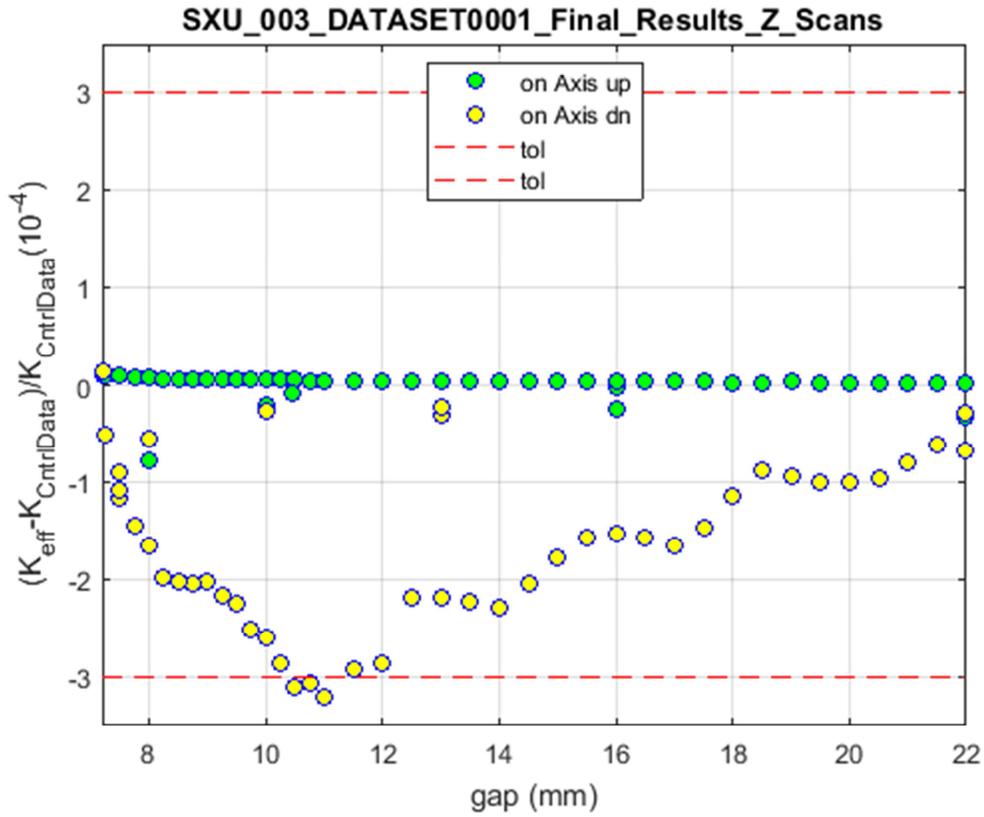


The figure shows the relative difference between the measured undulator strength K_{eff} and a cubic spline fit to the list of reference data points stored in file `sxu_003_k_vs_gap_spline.dat` in the Controls Data folder on the V: drive as a function of gap over the 7.2 mm – 22 mm operational range.

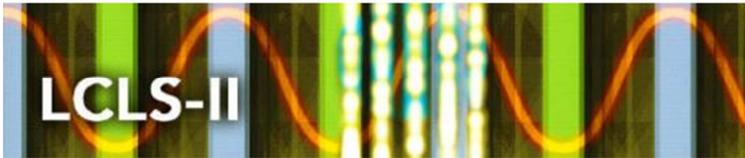
The legend explains the different cases that are shown in the plot: The green filled circles are data acquired on axis as the gap was changed from close to open. The yellow filled circles are data acquired on axis as the gap was changed from open to close. The horizontal red dashed lines show the tolerance limits. Note: The undulator K_{eff} value shows a hysteresis, i.e., for a given gap, the value depends on the direction of gap motion to reach that gap. While this is not a desirable feature, its effect stays within the given tolerance and will be acceptable. The other symbols shown indicate off-axis measurements that are added for interest only. The tolerance limits apply for on-axis readings, only



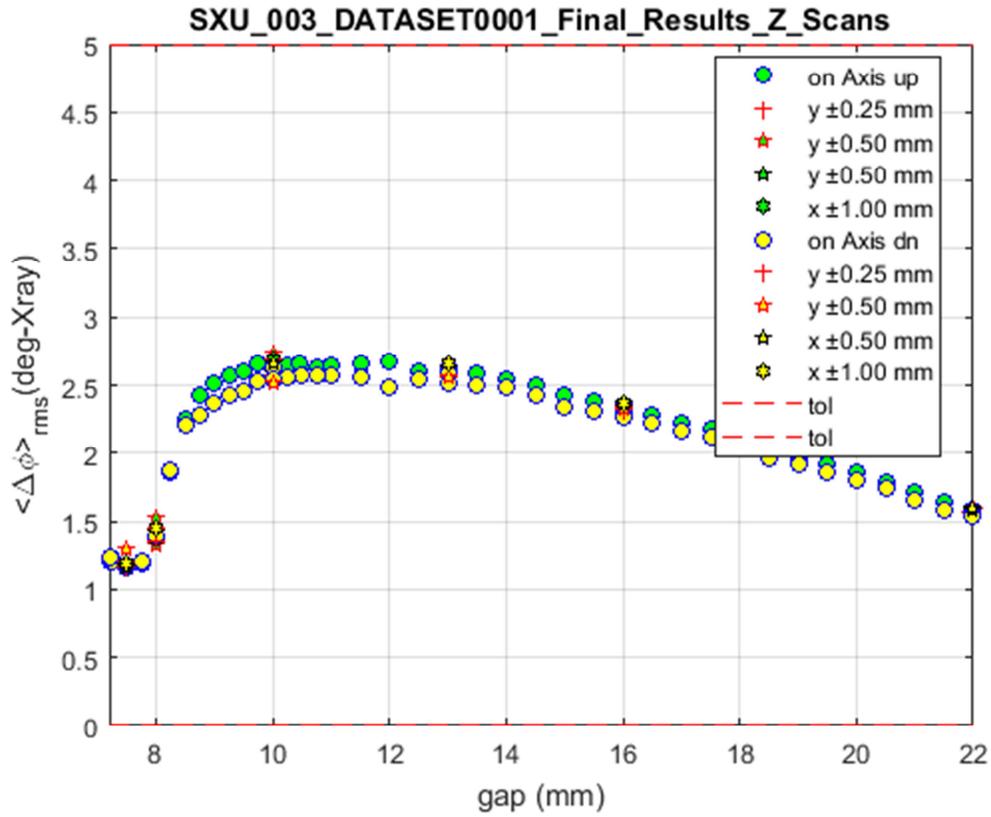
Evaluation of Hall Scans: $(K_{eff} - K_{CntrlData})/K_{CntrlData}$ vs *gap*



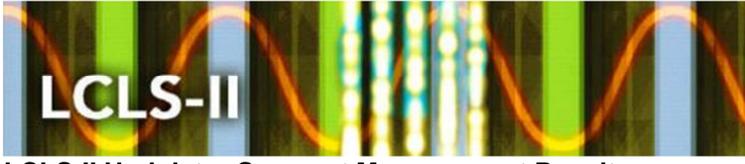
The figure shows some of the data shown in the previous figure but with a larger vertical scale that just captures the tolerance range. The hysteresis effect is more clearly visible. The off-axis measurements are not shown.



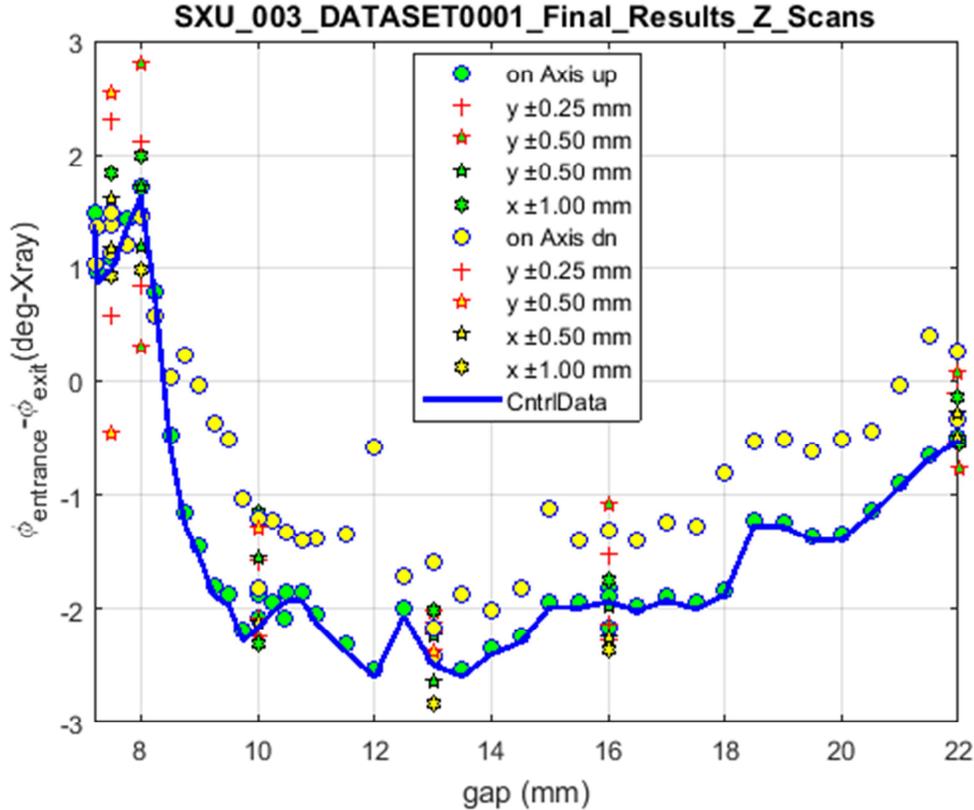
Evaluation of Hall Probe: Phase Shake vs. gap



The figure shows the phase shake, $\langle \Delta\phi \rangle_{rms}$, (see above) as a function of operational gap. The vertical axis extends over the entire tolerance range. The values show a slight hysteresis (show explanation above) but are well within tolerance.



Evaluation of Hall Probe: Entrance to Exit Phase Error Balance vs. gap



The figure shows a (negligible) imbalance of the entrance (cell boundary start to undulator core) to the exit (undulator core to cell boundary end) phase slippage for the undulator. In addition to the signals described above, the blue curve is a spline fit to the difference of the data in files

“..._phase_match_enter_vs_gap_spline.dat”

“..._phase_match_exit_vs_gap_spline.dat”.

The small change in phase difference between opening and closing measurements shows the effect of gap hysteresis. The explanation for the legend items can be found on previous pages above. The entrance and exit phase slippage is calculated as

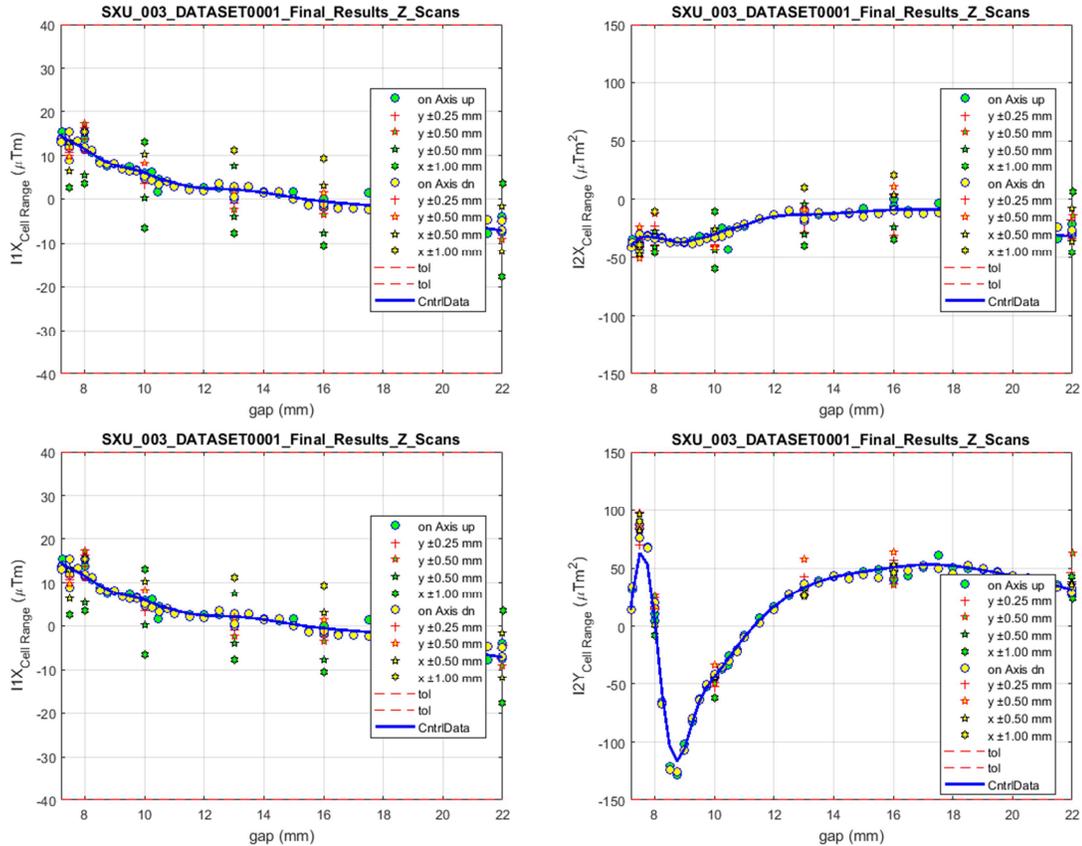
$$\phi_{entrance} = -\phi(z_{Cell-Start}) + \frac{1}{n+1} \sum_{j=1}^{n+1} (\phi(z_{B0,j}) - \pi(j-1)),$$

$$\phi_{exit} = \phi(z_{Cell-End}) - \frac{1}{n+1} \sum_{j=1}^{n+1} (\phi(z_{B0,j}) + \pi(n+1-j)).$$

Here, $z_{B0,j}$ is the z location of the zero crossing of $B_y(z)$ in front of the j^{th} core B_y peak. $z_{B0,(n+1)}$ is the z location of the field zero of $B_y(z)$ after the last core B_y peak.



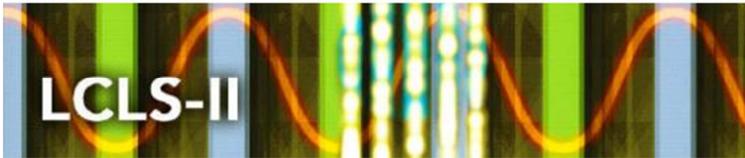
Evaluation of Hall Probe: Phase Integrals vs. gap



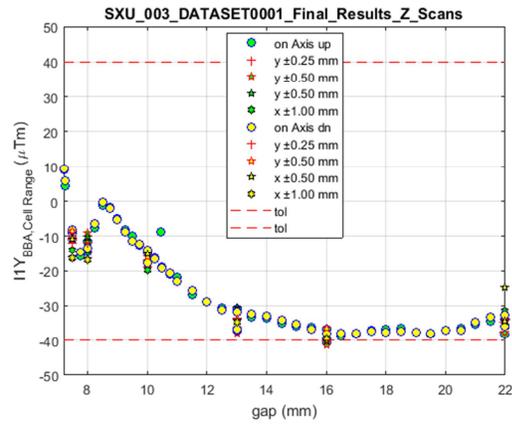
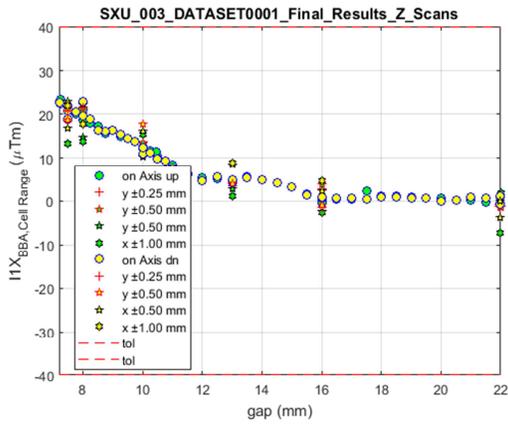
The figures show the phase integrals ($I1X$, $I2X$, $I1Y$, $I2Y$) as function of the operational gap. The proximity of the green and yellow circles shows that the field integrals are not sensitive to the hysteresis in K as seen on a previous page. The blue curves are spline fits to the data in files

- “...i1xvsgap_spline.dat”,
- “...i2xvsgap_spline.dat”,
- “...i1yvsgap_spline.dat”,
- “...i2yvsgap_spline.dat”,

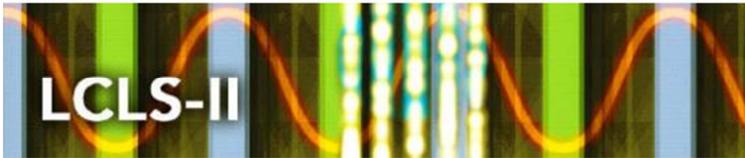
and demonstrate how the controls representations of the field integrals relates to the actual measurements (see final section of this document for file information).



Evaluation of Hall Probe: BBA Corrected Field Integrals

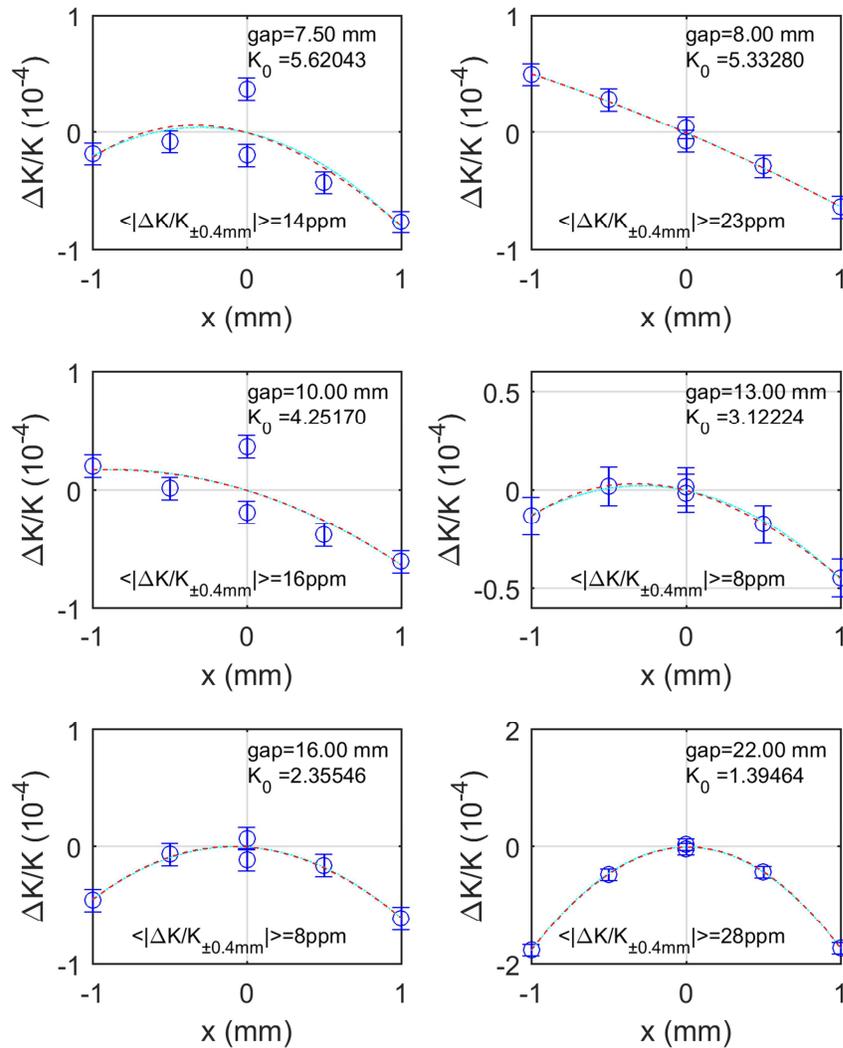


The figure shows the first integrals after a BBA equivalent correction was applied. The values stay within tolerance over the operational range.



Evaluation of Hall Probe: K vs. x dependence in y-z plane

SXU_003_DATASET0001_Final_Results_Z_Scans

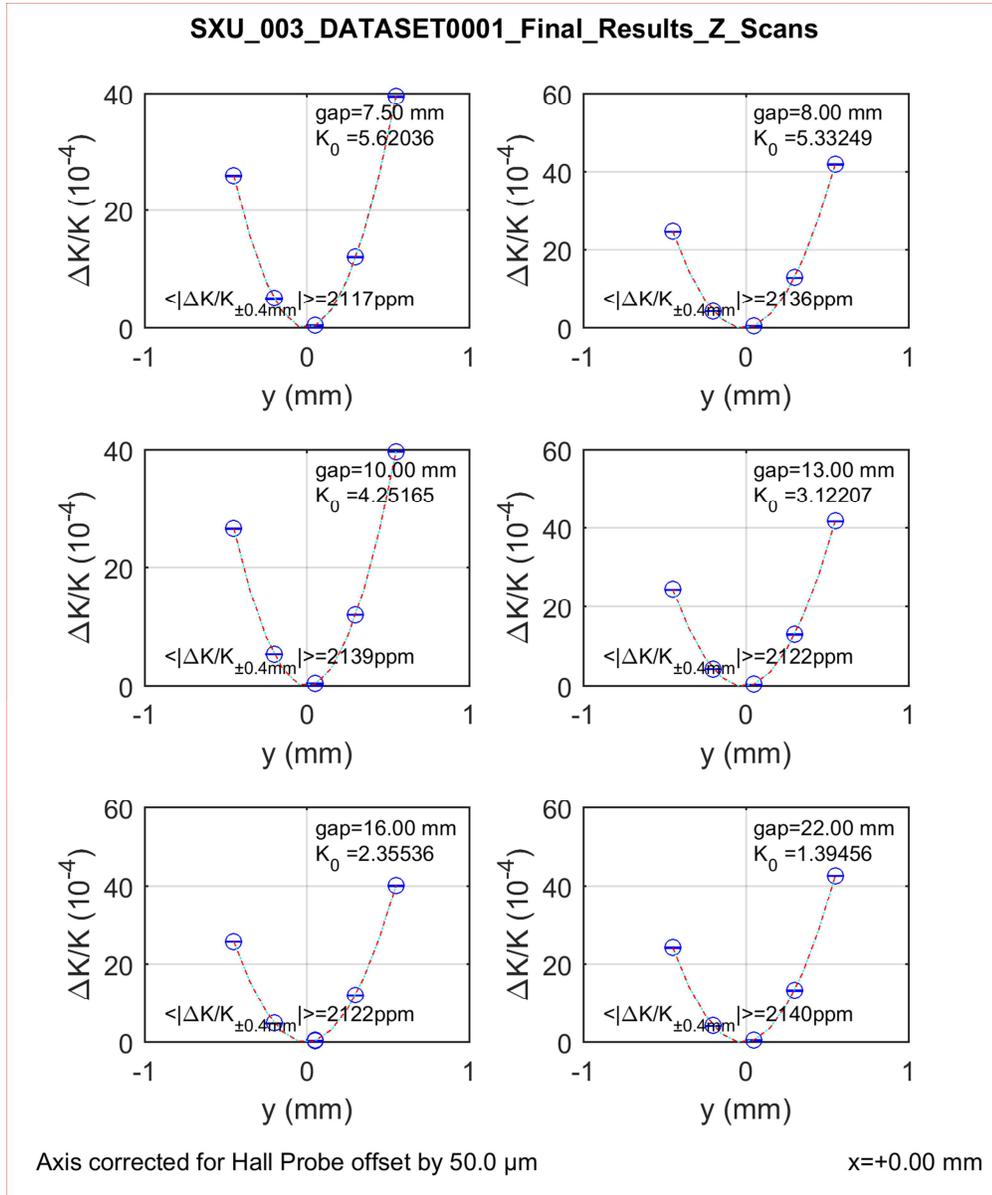
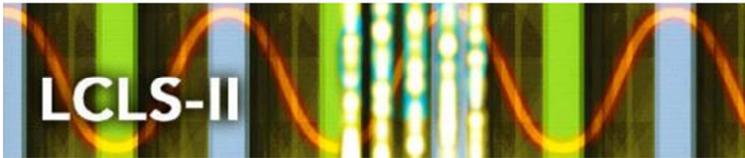


Axis corrected for Hall Probe offset by 0.0 μm

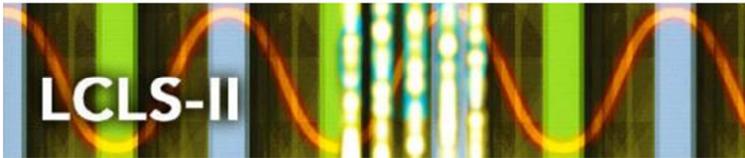
y=+0.00 mm

The figure shows the deviation of the relative K value from the off-axis K_0 as function of x in the y - z plane at a number of operational gaps. The average deviation at $z=0.4$ mm is well below the tolerance of 160 ppm in all cases.

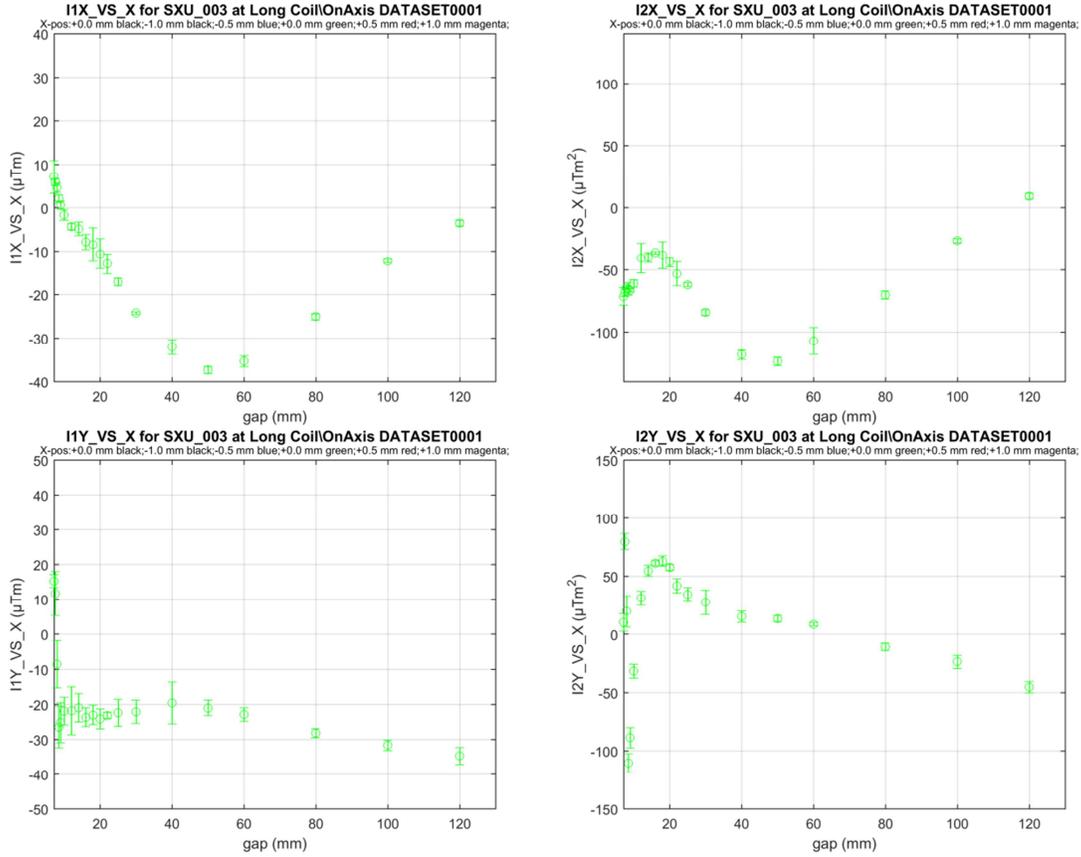
Evaluation of Hall Probe: K vs. y dependence in y-z plane



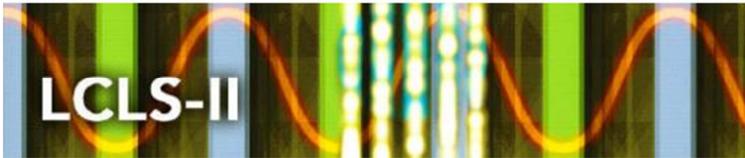
The figure shows the deviation of the relative K value from the off-axis K_0 as function of y in the y - z plane at a number of operational gaps. The deviations follow closely the expected functional form $(\cosh(k_u y) - 1)$. [Documentary Information]



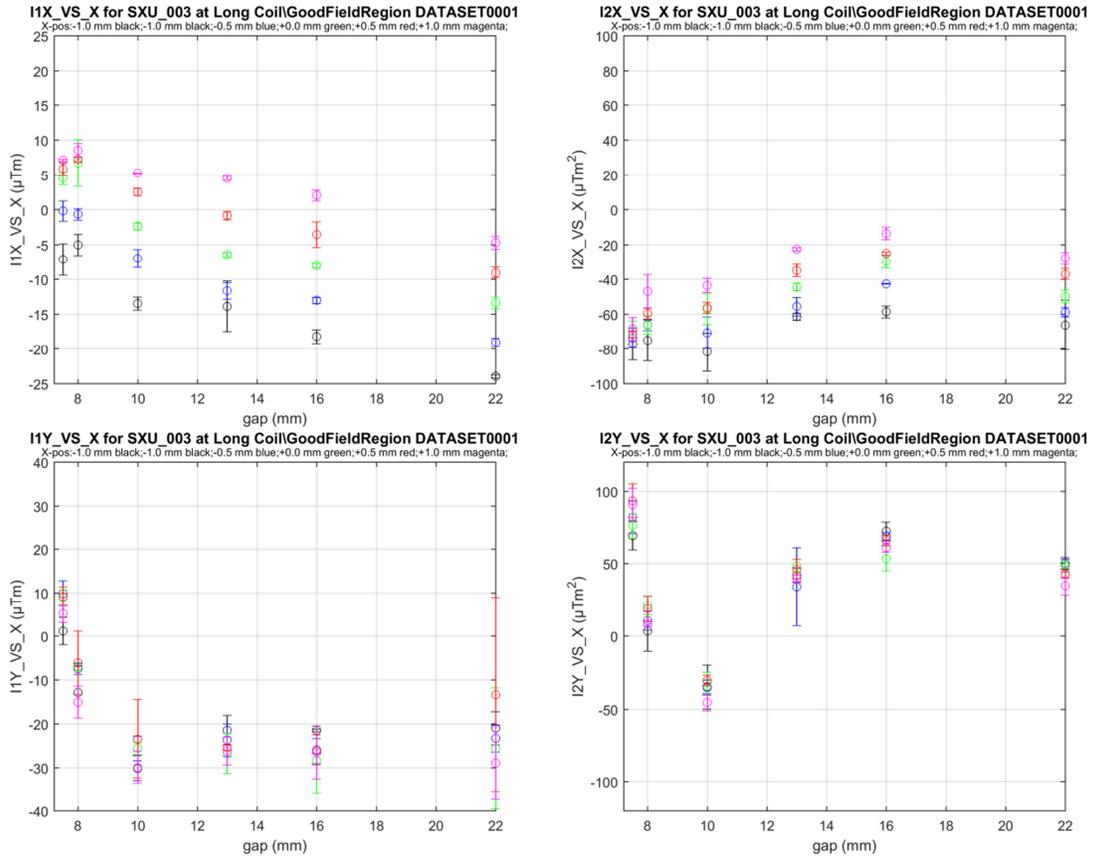
Long Coil Measurement of the On-Axis Field Integrals



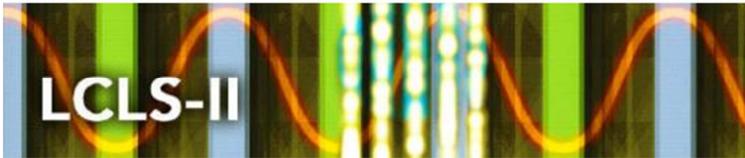
The figure shows the field integrals obtained from long coil measurements on-axis. The vertical axes extend over the tolerance range. All integrals are in tolerance.



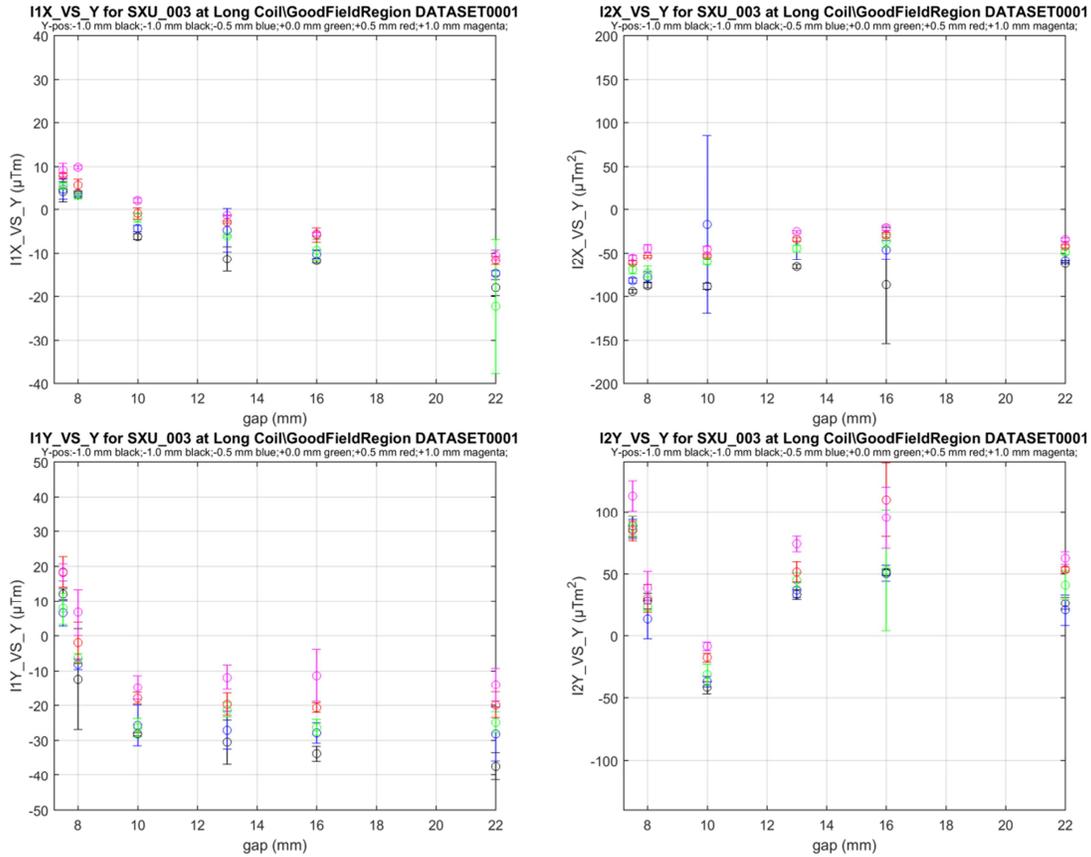
Long Coil Measurement of the Horizontally Off-Axis Field Integrals



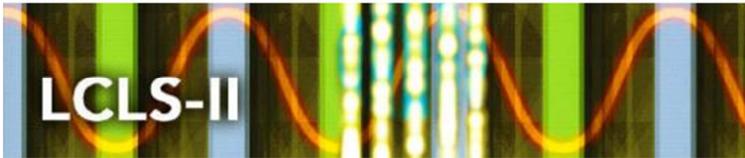
The figure shows the field integrals obtained from long coil measurements off axis in the horizontal plane using colors to indicate offset distance (black: -1.0 mm, blue: -0.5 mm, green: on-axis; red: +0.5 mm, magenta: +1.0 mm). The vertical axes extend over the tolerance range. All integrals are in tolerance.



Long Coil Measurement of the Vertically Off-Axis Field Integrals

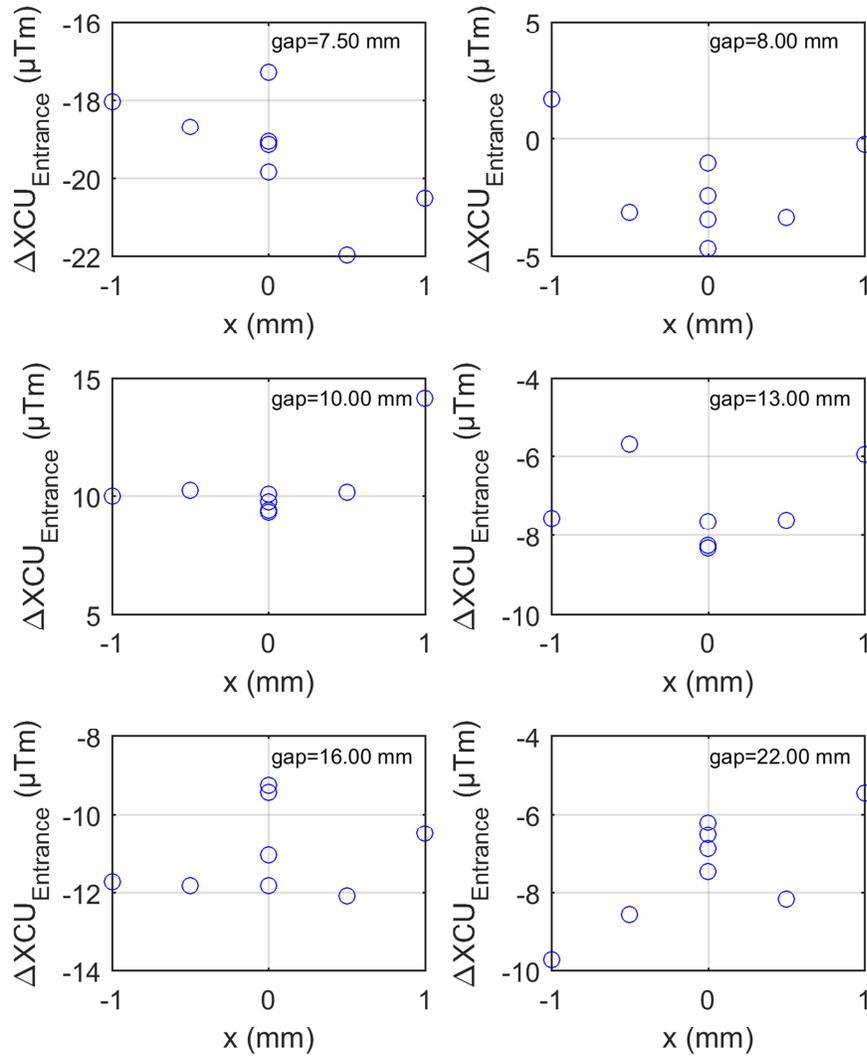


The figure shows the integrals obtained from long coil measurements off axis in the vertical plane using colors to indicate offset distance (black: -1.0 mm, blue: -0.5 mm, green: on-axis; red: +0.5 mm, magenta: +1.0 mm). The vertical axes extend of the tolerance range. All integrals are in tolerance.



Estimated Upstream Horizontal Corrector Strength Requirement vs. x

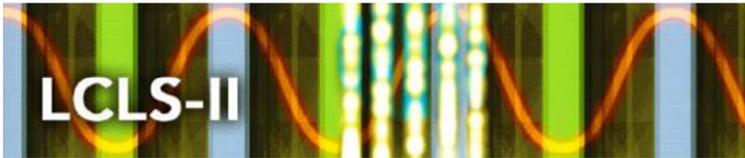
SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 0.0 μm

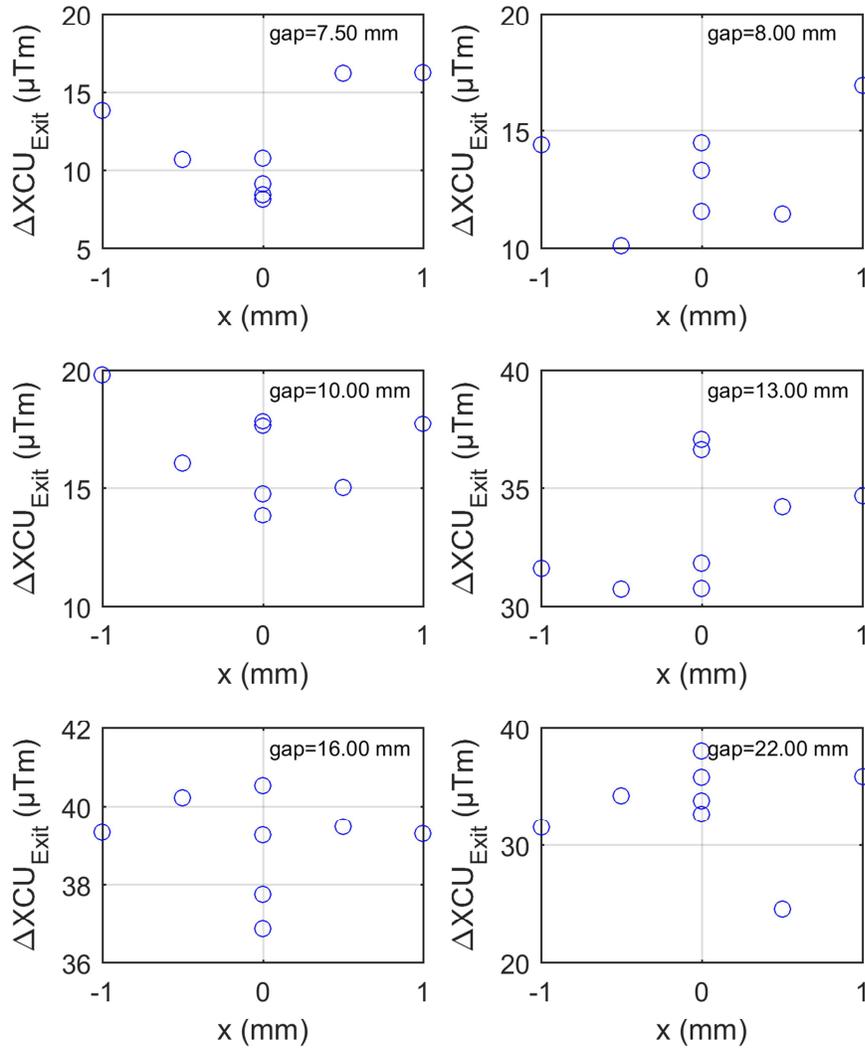
$y = +0.00$ mm

The figure shows the required strength of the upstream horizontal corrector to remove the second vertical undulator field integral at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the x-z plane. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.



Estimated Downstream Horizontal Corrector Strength Requirement vs. x

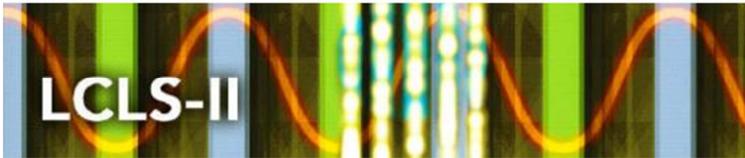
SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 0.0 μm

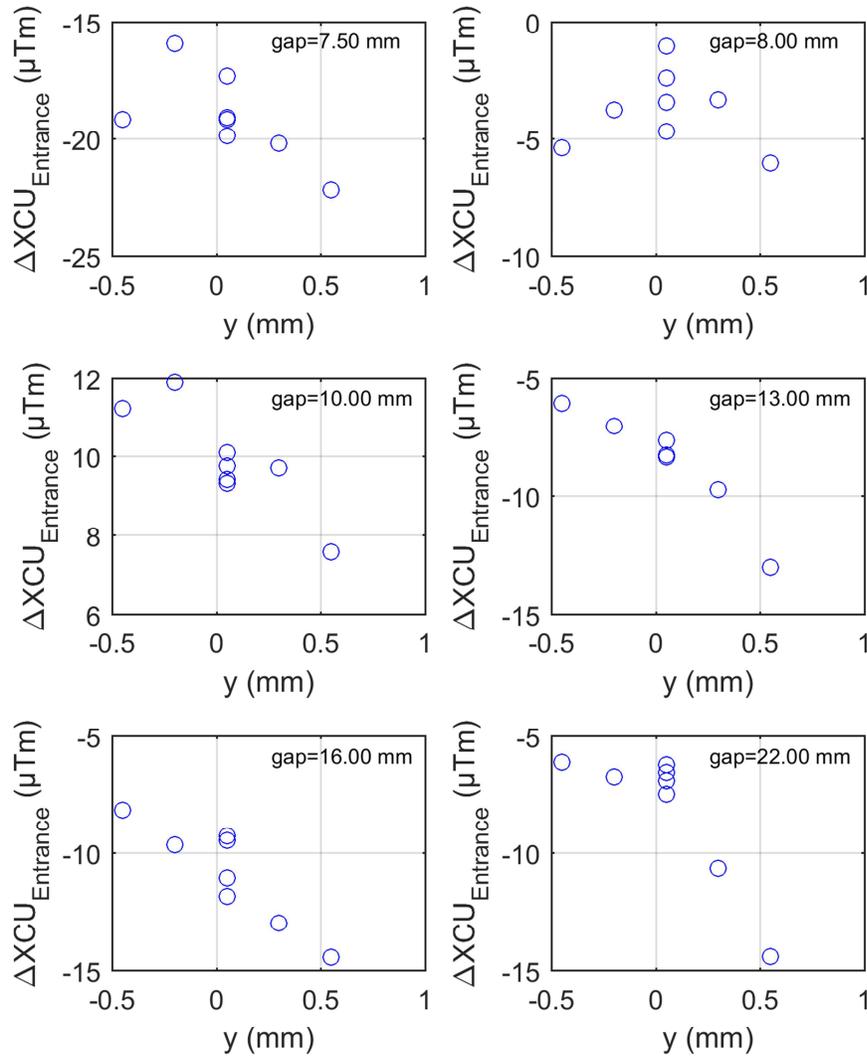
$y = +0.00$ mm

The figure shows the required strength of the downstream horizontal corrector to remove the first vertical undulator and upstream corrector field integrals at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the x-z plane. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.



Estimated Upstream Horizontal Corrector Strength Requirement vs. y

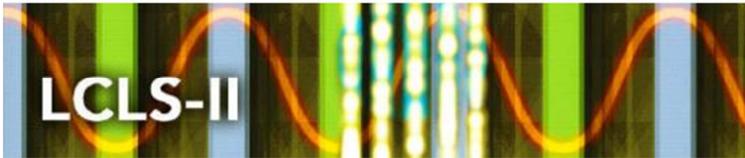
SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 50.0 μm

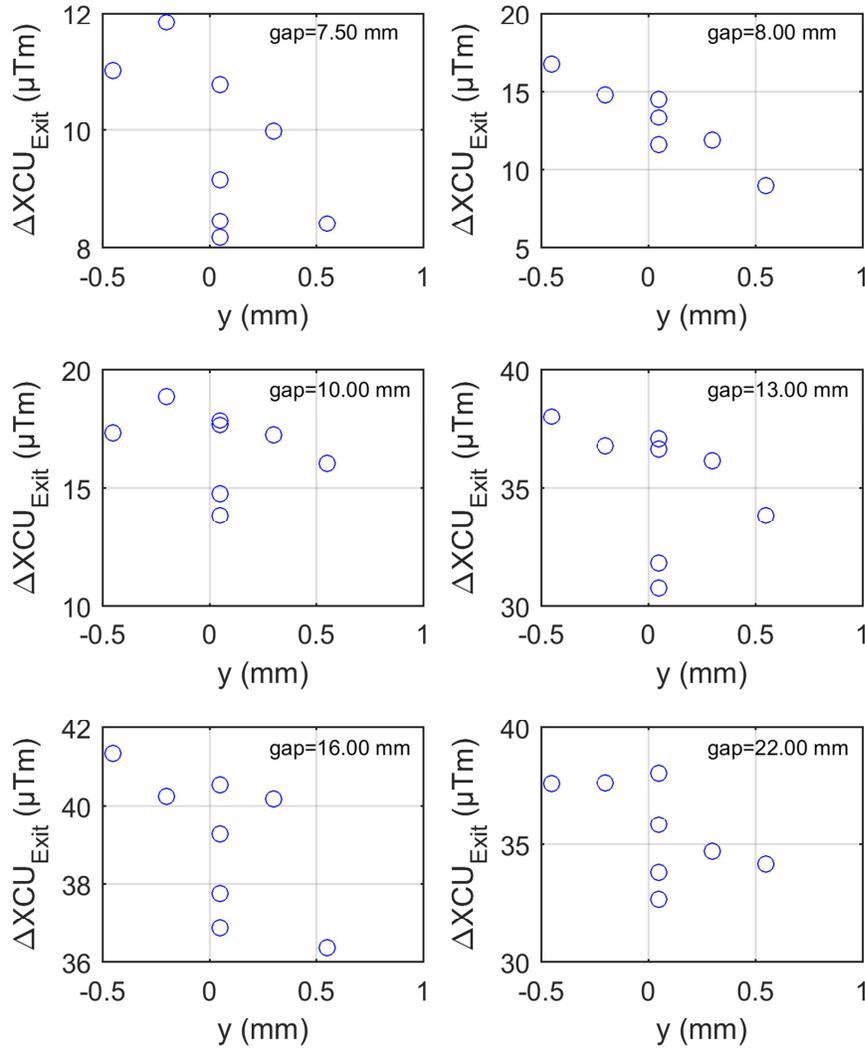
x=+0.00 mm

The figure shows the required strength of the upstream horizontal corrector to remove the second vertical undulator field integrals at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the y-z plane. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.



Estimated Downstream Horizontal Corrector Strength Requirement vs. y

SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 50.0 μm

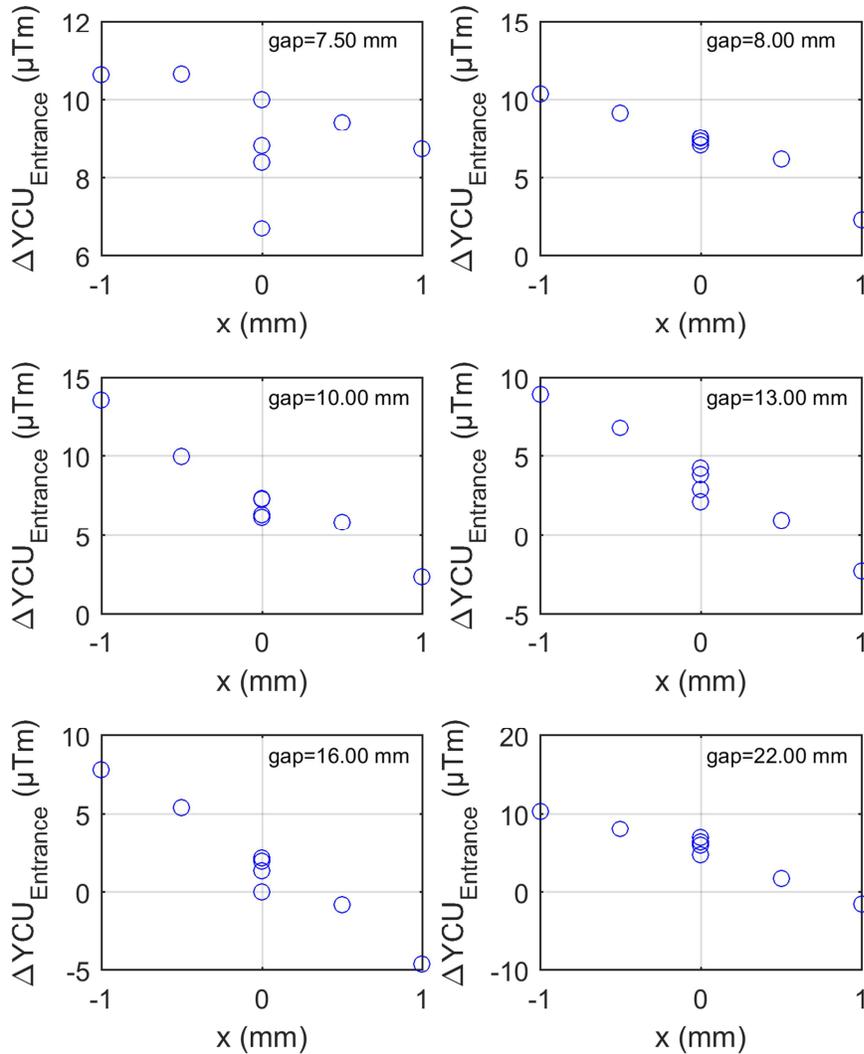
$x=+0.00$ mm

The figure shows the required strength of the upstream horizontal corrector to remove the first vertical undulator and upstream corrector field integrals at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the y-z plane. All values are small and well below the maximum correction amplitude of greater than 550 μTm capabilities of the actual correctors.



Estimated Upstream Vertical Corrector Strength Requirement vs. x

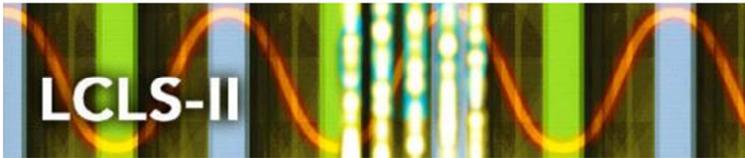
SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 0.0 μm

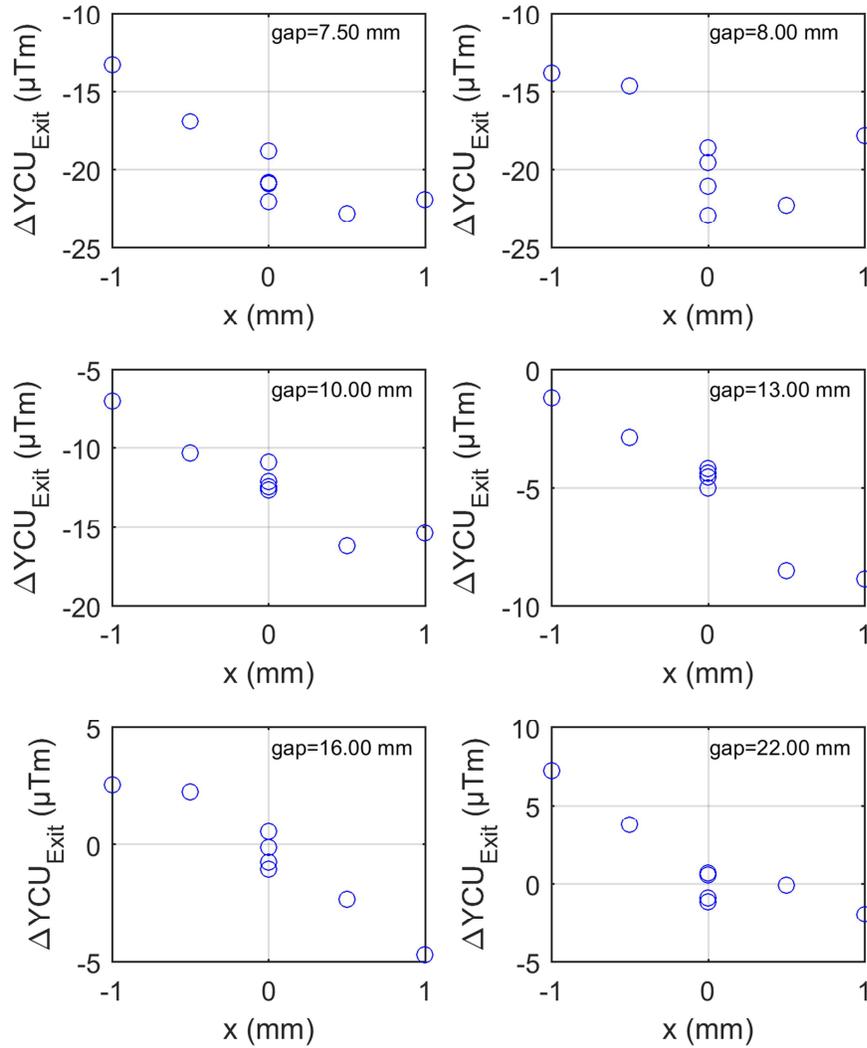
y=+0.00 mm

The figure shows the required strength of the upstream horizontal corrector to remove the second horizontal undulator field integral at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the x-z plane. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.



Estimated Downstream Vertical Corrector Strength Requirement vs. x

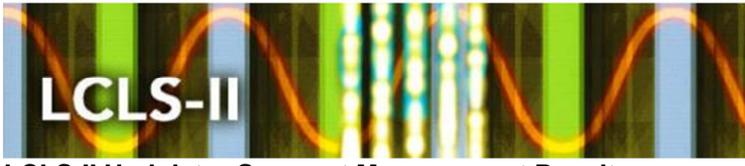
SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 0.0 μm

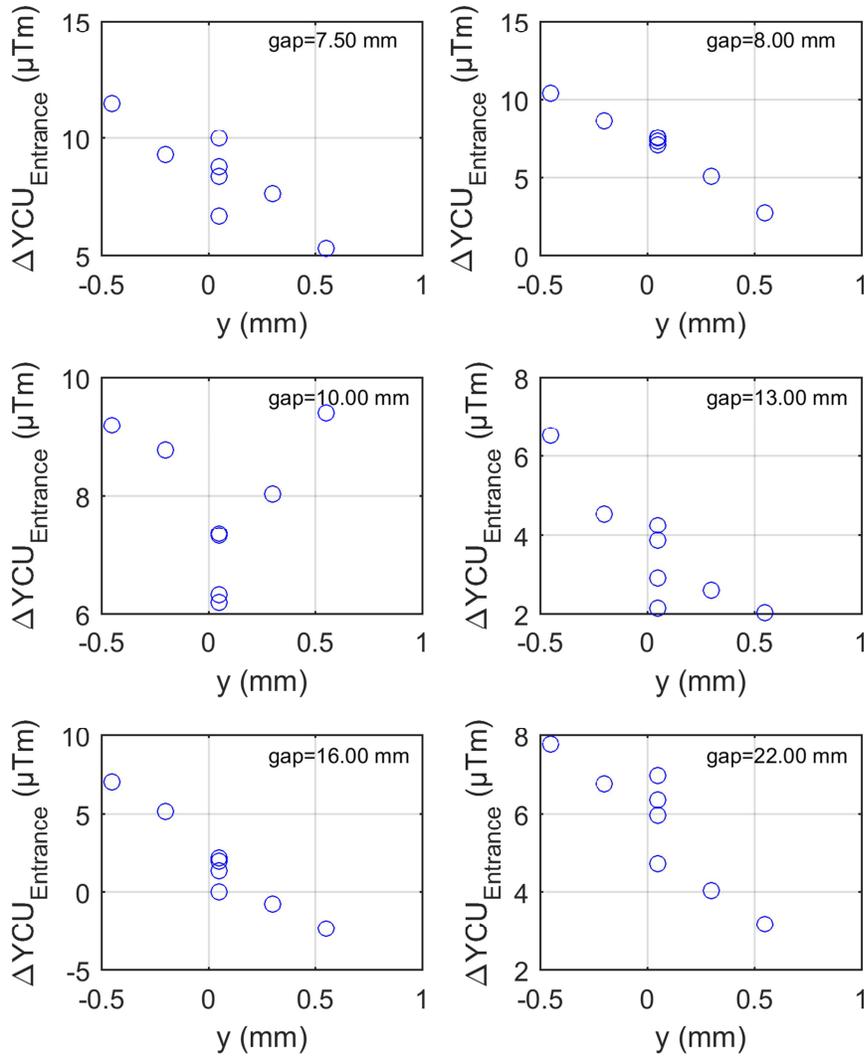
y=+0.00 mm

The figure shows the required strength of the downstream vertical corrector to remove the first horizontal undulator and upstream corrector field integrals at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the x-z plane. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.



Estimated Upstream Vertical Corrector Strength Requirement vs. y

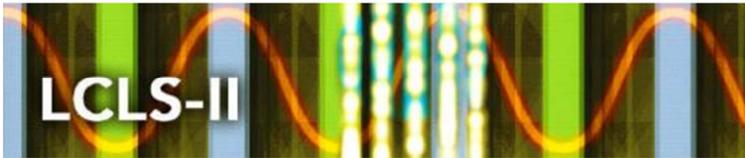
SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 50.0 μm

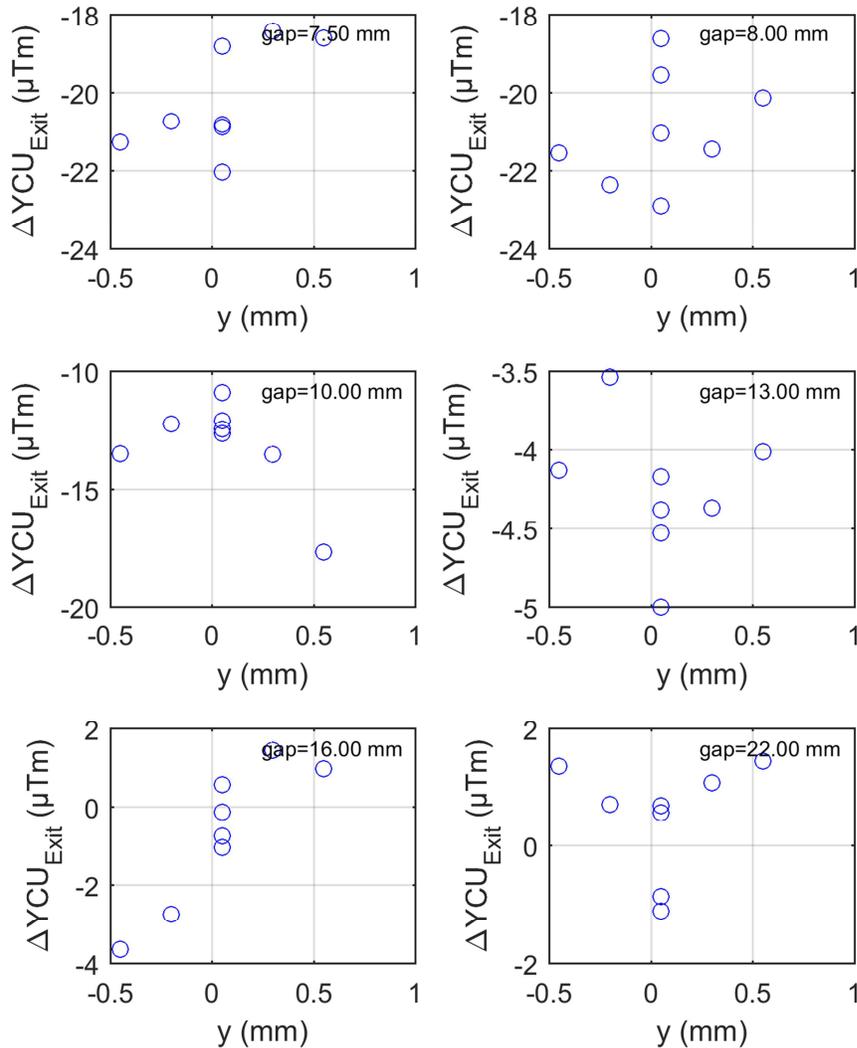
x=+0.00 mm

The figure shows the required strength of the upstream vertical corrector to remove the second horizontal undulator field integral at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the y-z plane. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.



Estimated Downstream Vertical Corrector Strength Requirement vs. y

SXU_003_DATASET0001_Final_Results_Z_Scans



Axis corrected for Hall Probe offset by 50.0 μm

x=+0.00 mm

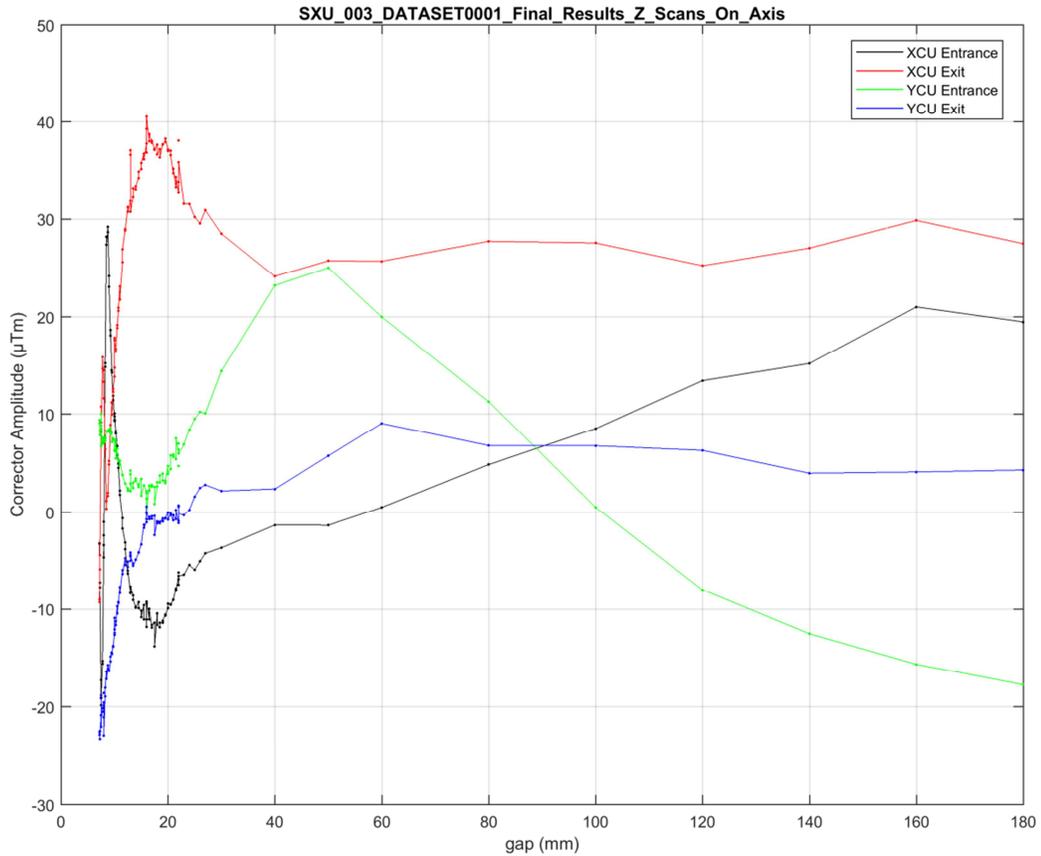
The figure shows the required strength of the downstream vertical corrector to remove the first horizontal undulator and upstream corrector field integrals at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the y-z plane. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.

Estimated Corrector Strengths Requirement vs. gap

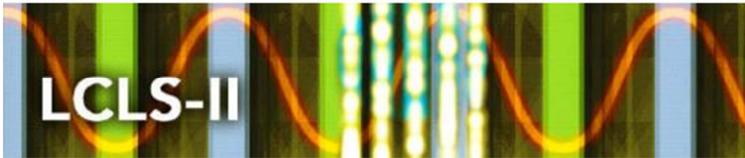


LCLS-II Undulator Segment Measurement Results

SXU-003



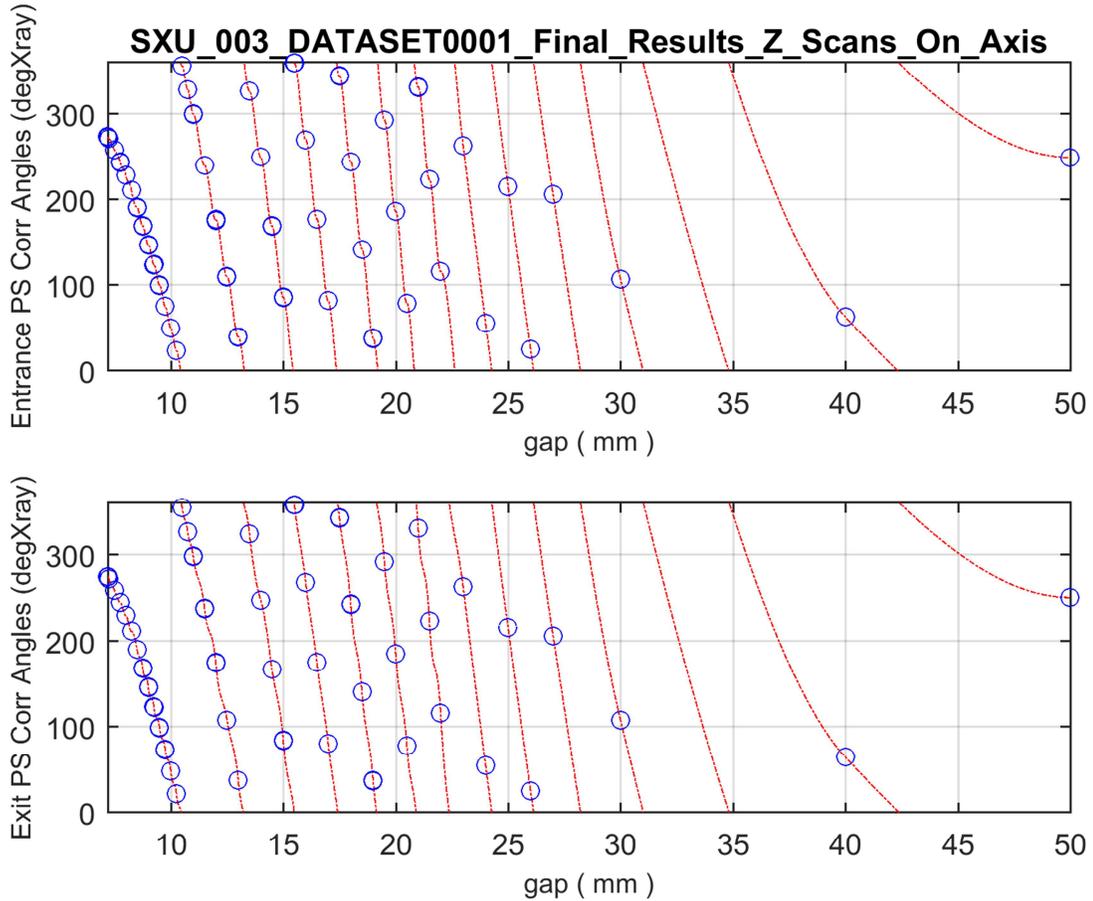
The figure shows as a function of undulator gap the required strengths of the upstream and downstream horizontal and vertical correctors to remove the effect of undulator field integrals at the downstream BPM over the entire available gap range. All values are small and well below the maximum correction capabilities of greater than 550 μTm of the actual correctors.



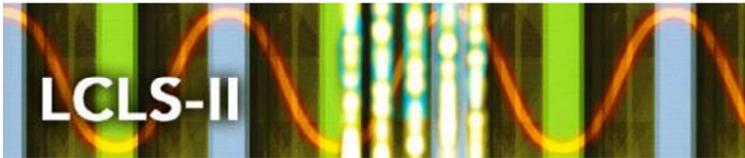
LCLS-II Undulator Segment Measurement Results

SXU-003

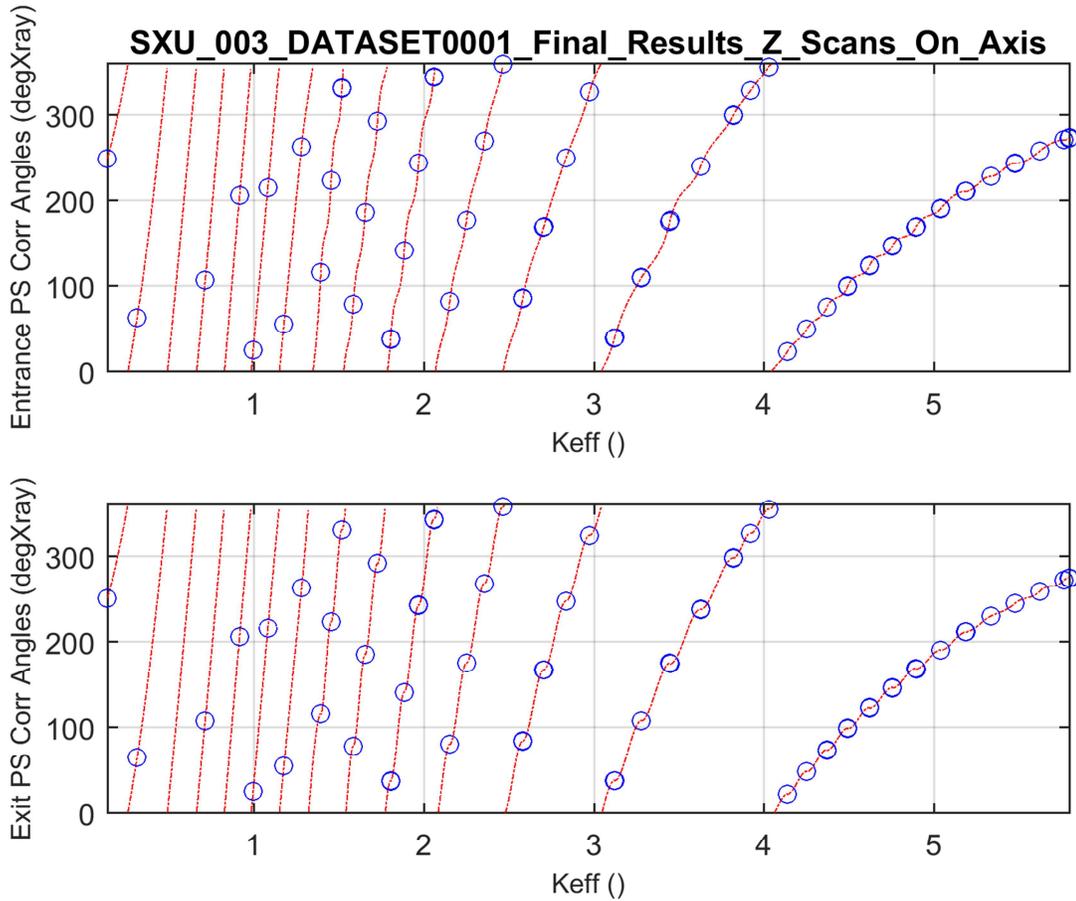
Estimated Phase Shifter (Angle) Change Requirement vs. gap



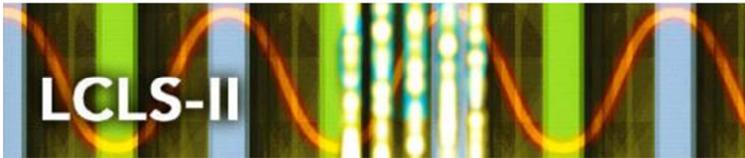
The top and bottom figures show as a function of undulator gap the required correction angles to be added to the upstream and downstream phase shifters, respectively. The red lines indicate the minimum required phase shifter phase angle increases, which are in the 0 to 360 degXray phase shift range. The blue circles indicate MMF measurements.



Estimated Phase Shifter (Angle) Change Requirement vs. K_{eff}



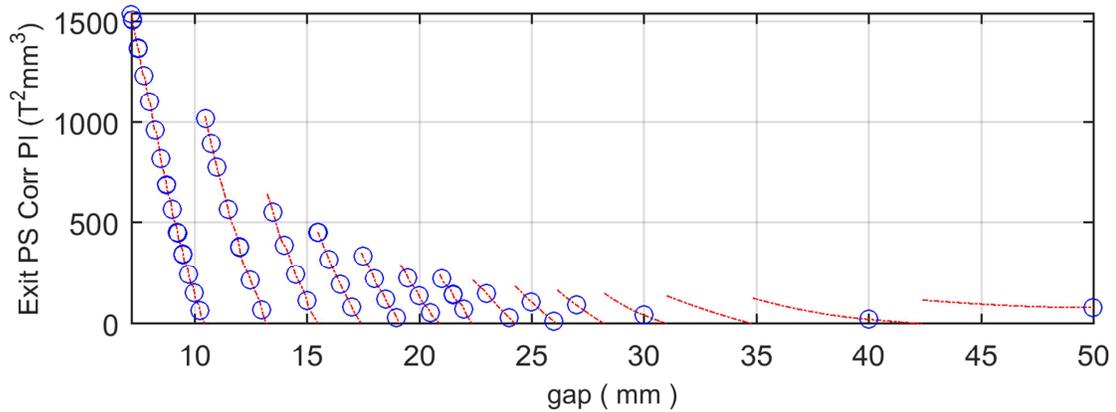
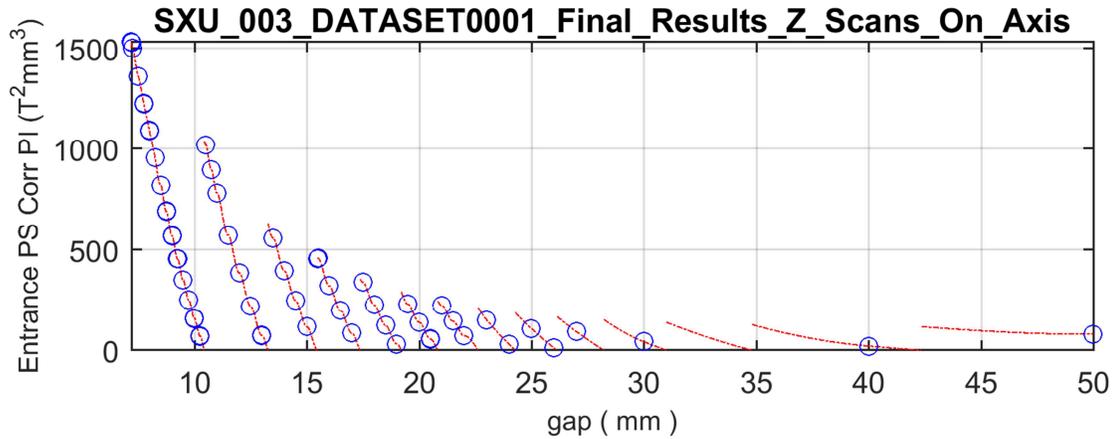
The top and bottom figures as a function of undulator parameter K_{eff} the required correction angles to be added to the upstream and downstream phase shifters, respectively. The red lines indicate the minimum required phase shifter phase angle increases, which are in the 0 to 360 degXray phase shift range. The blue circles indicate MMF measurements.



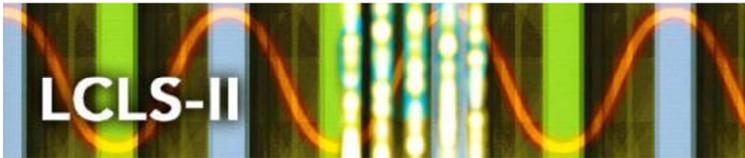
LCLS-II Undulator Segment Measurement Results

SXU-003

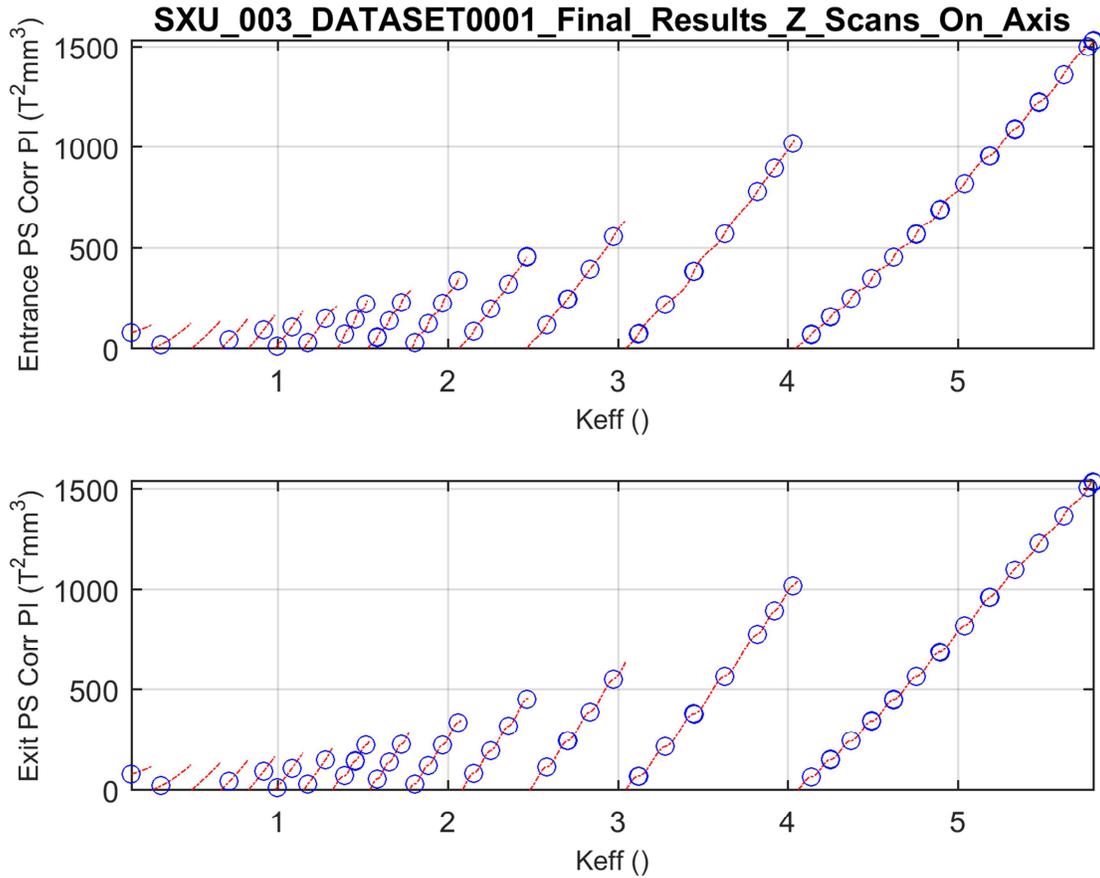
Estimated Phase Shifter (Phase Integral Change) Requirement vs. gap



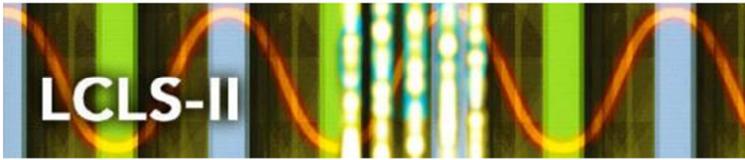
The top and bottom figures show as a function of undulator gap the required correction phase integral (PI) values to be added to the upstream and downstream phase shifters, respectively. The red lines indicate the minimum required phase shifter phase angle increases, which are in the 0 to 360 degXray phase shift range. The blue circles indicate MMF measurements.



Estimated Phase Shifter (Angle) Requirement vs. gap



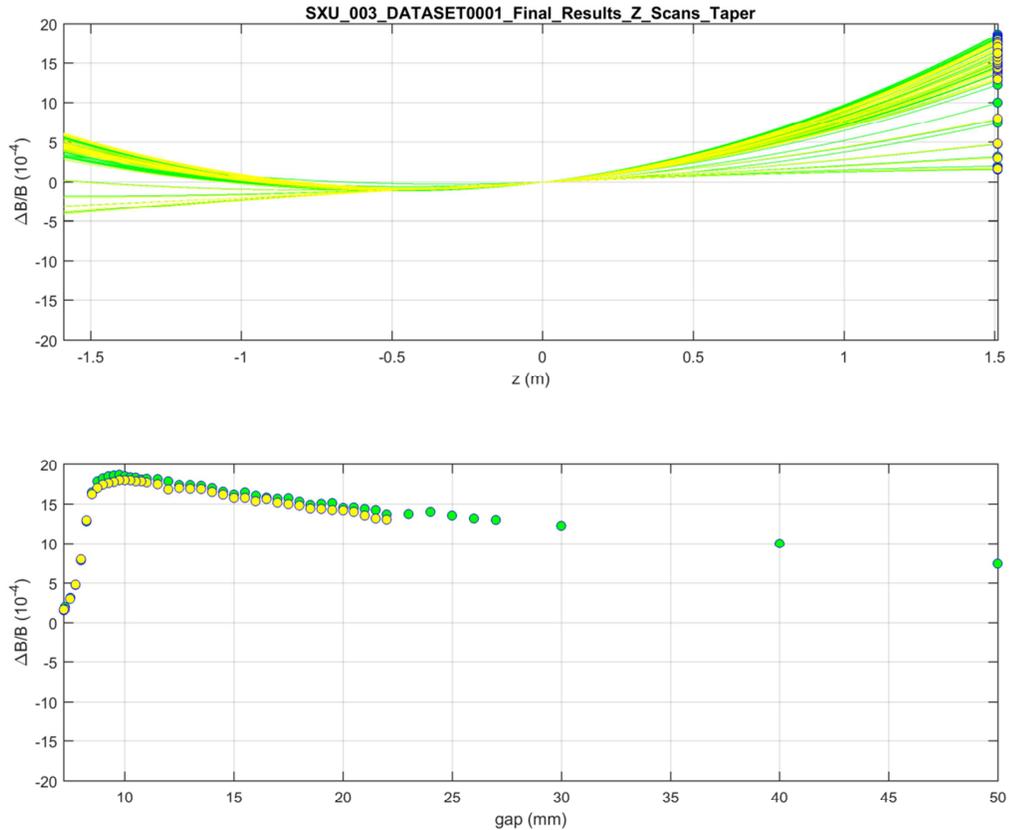
The top and bottom figures show as a function of undulator parameter K_{eff} the required correction phase integral (PI) values to be added to the upstream and downstream phase shifters, respectively. The red lines indicate the minimum required phase shifter phase angle increases, which are in the 0 to 360 degXray phase shift range. The blue circles indicate MMF measurements.



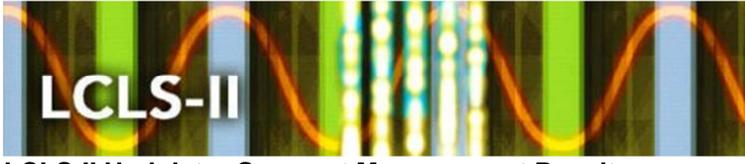
LCLS-II Undulator Segment Measurement Results

SXU-003

Zero Taper Fits vs. gap



The top figure shows quadratic fits to the absolute values K_u for each core pole for different gaps when the device is set to zero taper. Green curves indicate that the gap was approached from smaller gaps, while yellow curves indicate approach from larger gaps. The fitted K_u value of the last pole is marked with a solid circle with the same color coding. The bottom shows the same solid circles as in the upper plot but this time plotted against the corresponding undulator gap encoder values. The figures show that the undulator has a small quadratic taper that varies with gap. This could explain the phase shake dependence on gap as shown in an earlier figure.



LCLS-II Undulator Segment Measurement Results

SXU-003

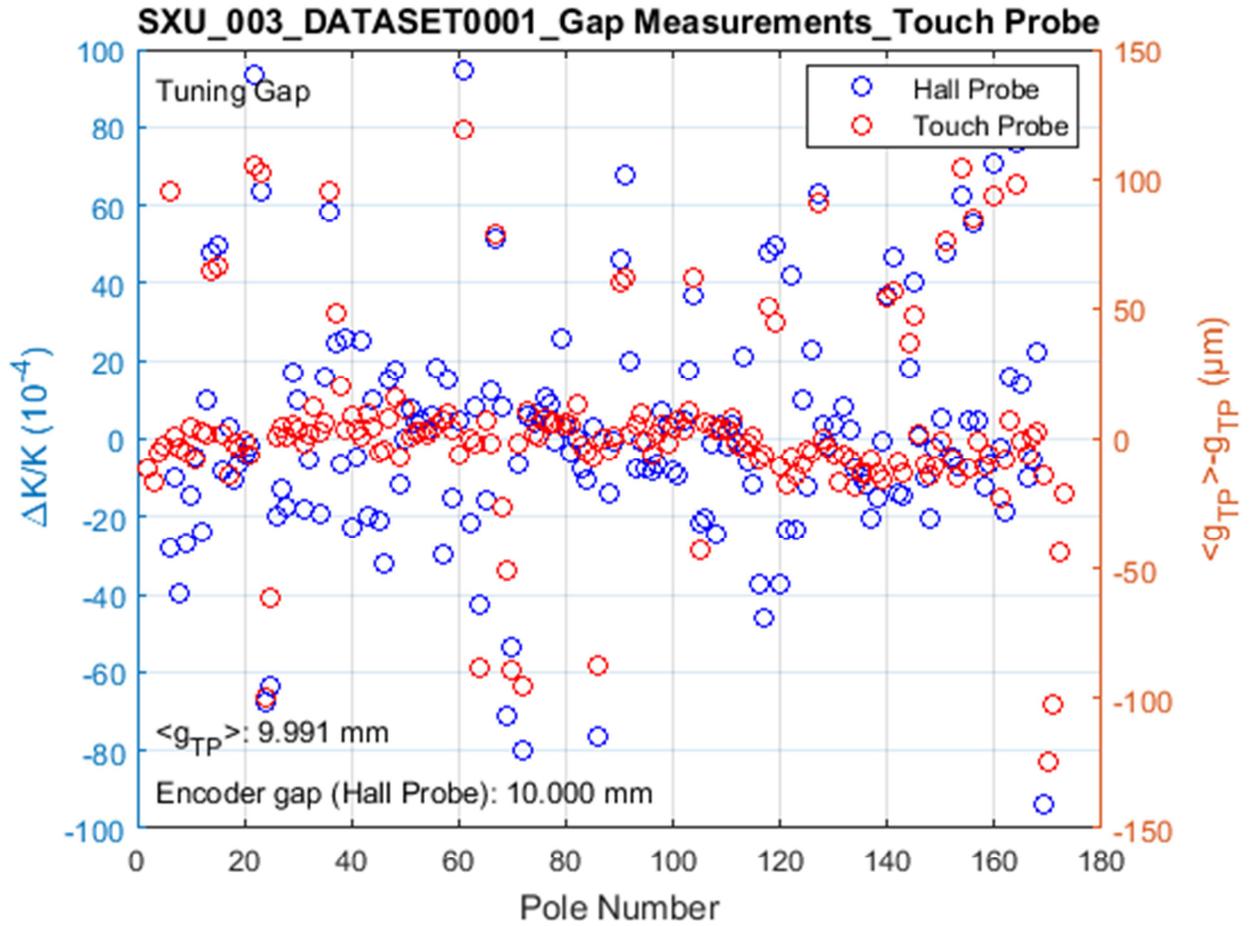
Tapered Operation

Tapered Operation has not yet been analyzed for SXU-003.

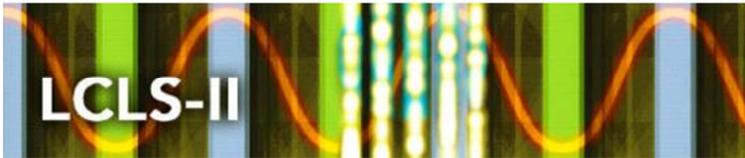


LCLS-II Undulator Segment Measurement Results

SXU-003

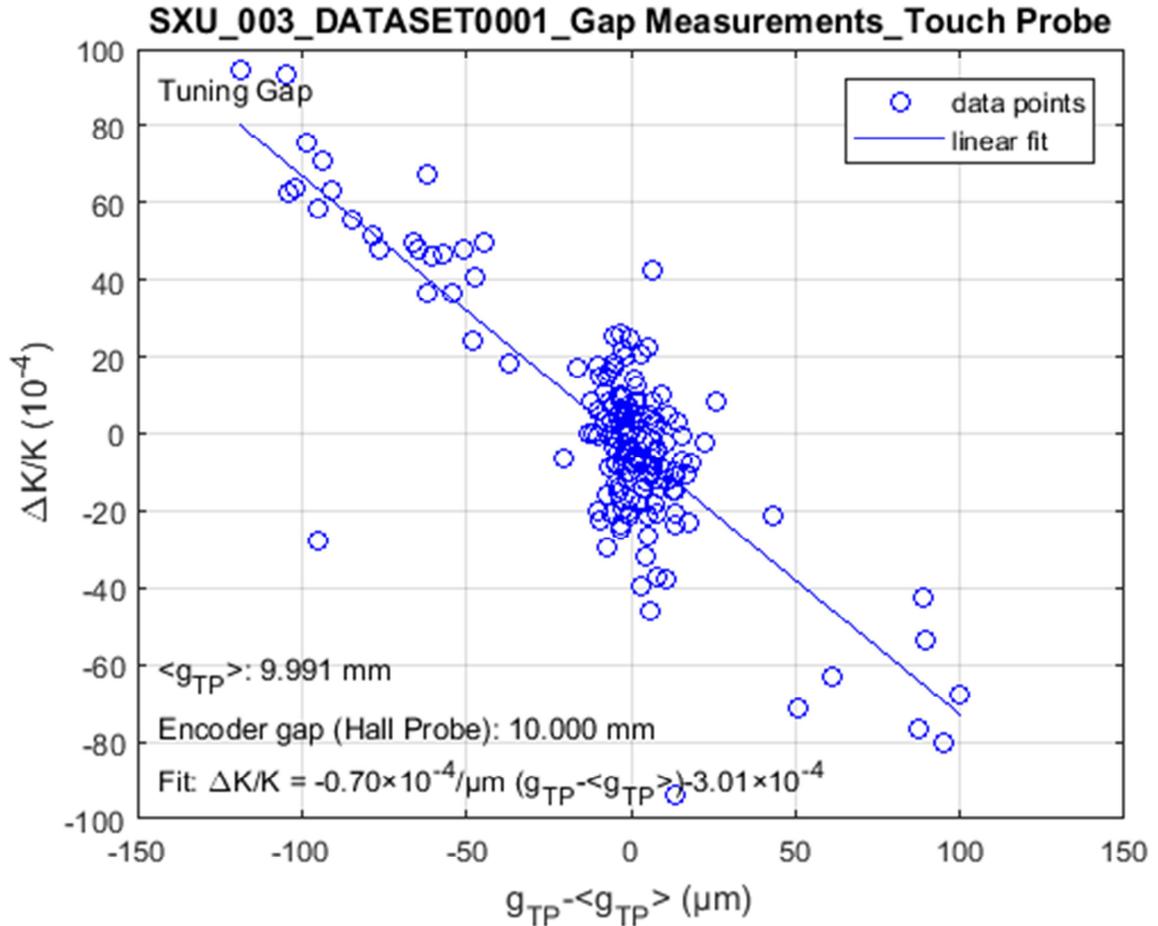


The figure shows $\Delta K/K$ (blue, left axis) (for the 164 central poles) as well as mechanical gap heights $\langle g_{TP} \rangle - g_{TP}$ (red, right axis) (for all 174 poles) based on touch probe measurements versus pole number. The large amplitude outliers are the result of tuning.

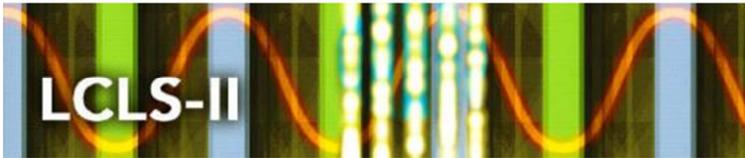


LCLS-II Undulator Segment Measurement Results

SXU-003

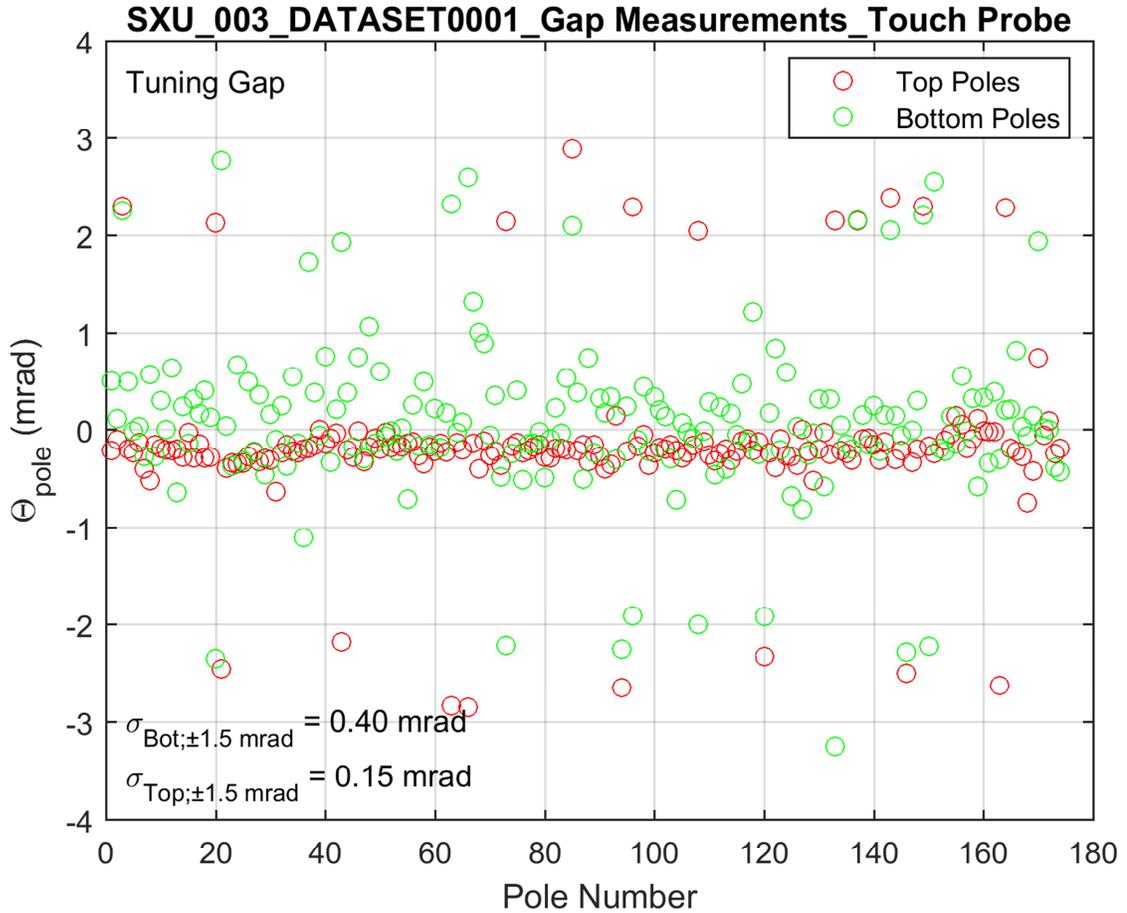


The figure shows the correlation between the $\Delta K_u/K_u$ for each pole from Hall probe measurements for the tuning gap and the deviation of the pole gap measured by the touch probe relative to its average (for the 164 core poles). The average gap measured with the touch probe and the one measured with the gap encoder are shown in the lower left corner of the figure. Also shown is the fit function.

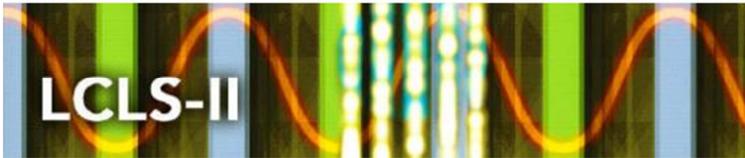


LCLS-II Undulator Segment Measurement Results

SXU-003

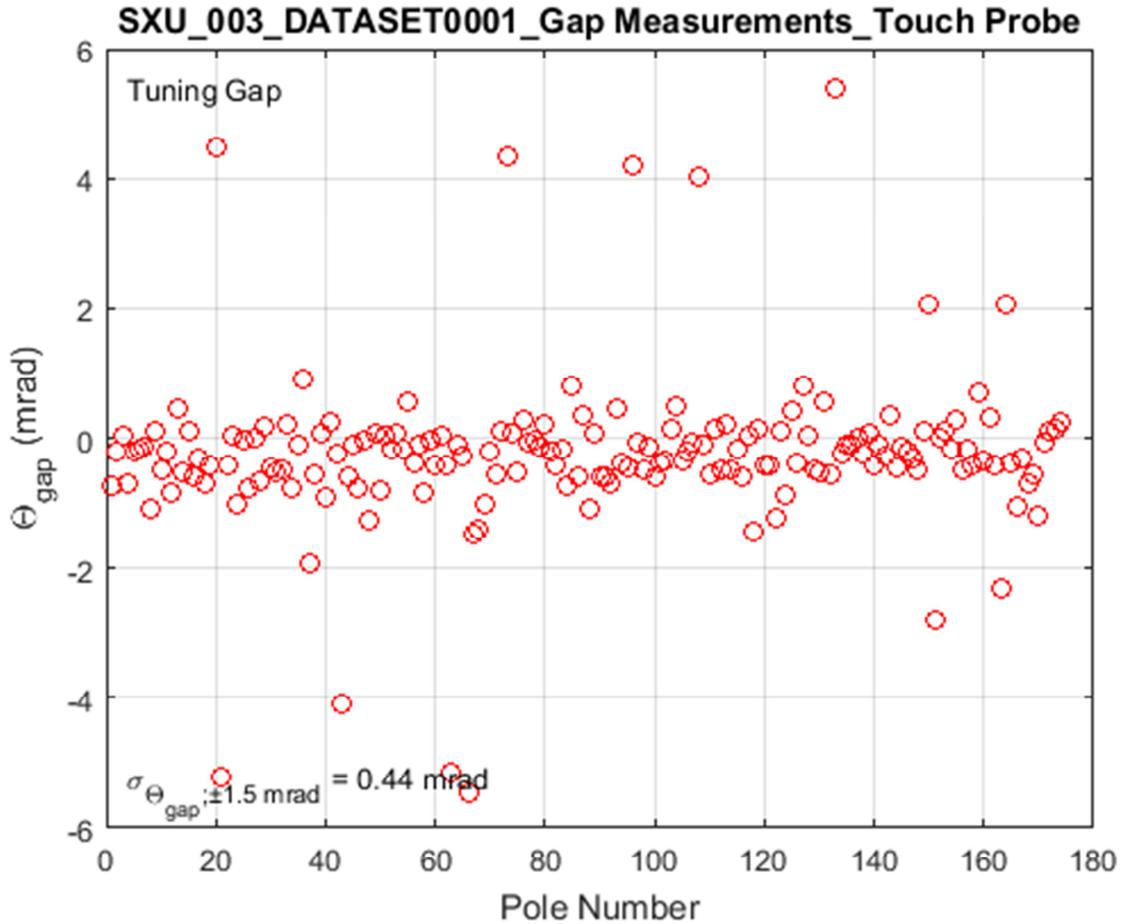


The figure shows the cant angles of each pole (top red, bottom green) relative to the horizontal plane defined by the Kugler bench at the Tuning Gap for all 174 poles, measured by the touch probe. The rms width of each distribution within a ± 1.5 mrad band is shown in the lower left corner of the figure. Note: that the distribution of the top pole angles is almost 3 times wider than that of the bottom pole angles. Not clear what the reason for this is.

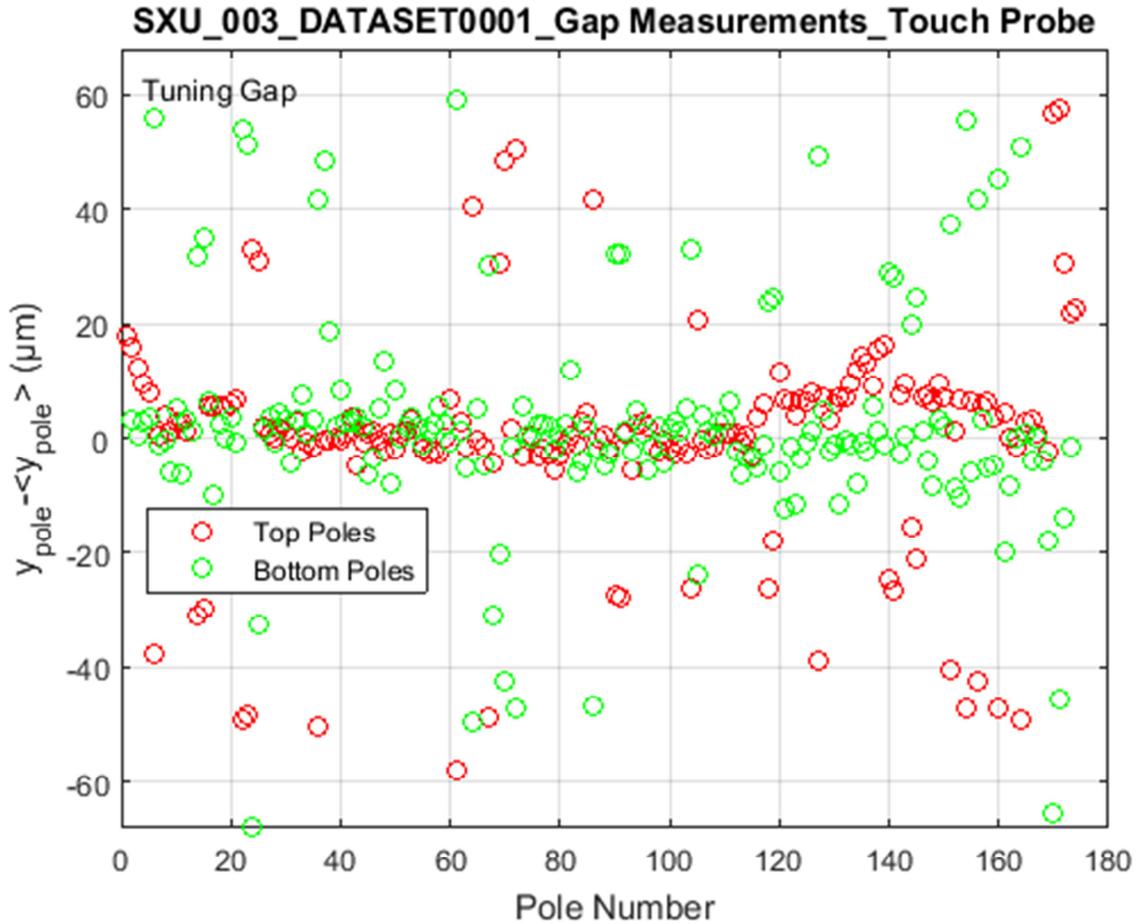
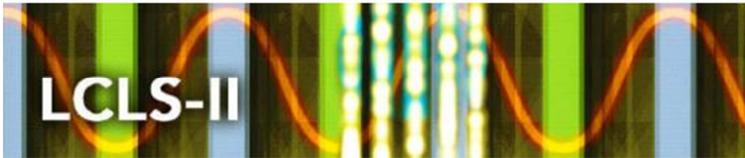


LCLS-II Undulator Segment Measurement Results

SXU-003



The figure shows the cant angles between the top and bottom part of each pole at the Tuning Gap for all 174 poles, measured by the touch probe. The rms width of the distribution within a ± 1.5 mrad band is shown in the lower left corner of the figure.



The figure shows the relative vertical positions of the center of each pole (top red, bottom green) relative to the horizontal plane defined by the Kugler bench at the Tuning Gap for all 174 poles, measured by the touch probe. Note: The right most upper magnet module appears to be mounted too high by almost 10 μm relative to the others.



LCLS-II Undulator Segment Measurement Results

SXU-003

Measurement Results are stored:

At V-Drive:

V:\MET\MagServe\MagData\LCLS-II\Undulator\

In Folder:

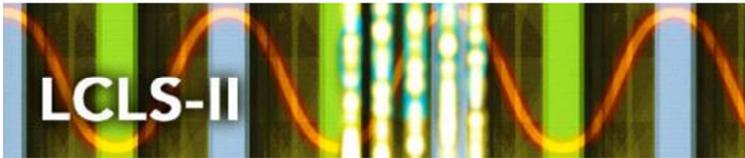
SXU_003\DATASET0001\Final Results\

Confirmation of File Locations:

The following lists all required data files documenting the tuning results. An existence check was done and the result is indicated next to each filename as “exists” or “missing”.

Sub folder: Z Scans\Good Field Region exists

001gap007.500x-01.00y+00.00\zscan.dat	exists
002gap007.500x-00.50y+00.00\zscan.dat	exists
003gap007.500x+00.00y+00.00\zscan.dat	exists
004gap007.500x+00.50y+00.00\zscan.dat	exists
005gap007.500x+01.00y+00.00\zscan.dat	exists
031gap007.500x+00.00y-00.50\zscan.dat	exists
003gap007.500x+00.00y+00.00\zscan.dat	exists
035gap007.500x+00.00y+00.50\zscan.dat	exists
006gap008.000x-01.00y+00.00\zscan.dat	exists
007gap008.000x-00.50y+00.00\zscan.dat	exists
008gap008.000x+00.00y+00.00\zscan.dat	exists
009gap008.000x+00.50y+00.00\zscan.dat	exists
010gap008.000x+01.00y+00.00\zscan.dat	exists
036gap008.000x+00.00y-00.50\zscan.dat	exists
008gap008.000x+00.00y+00.00\zscan.dat	exists
040gap008.000x+00.00y+00.50\zscan.dat	exists
011gap010.000x-01.00y+00.00\zscan.dat	exists
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013gap010.000x+00.00y+00.00\zscan.dat	exists



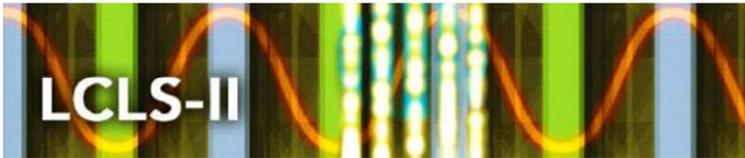
LCLS-II Undulator Segment Measurement Results

SXU-003

014gap010.000x+00.50y+00.00\zscan.dat	exists
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041gap010.000x+00.00y-00.50\zscan.dat	exists
013gap010.000x+00.00y+00.00\zscan.dat	exists
045gap010.000x+00.00y+00.50\zscan.dat	exists
016gap013.000x-01.00y+00.00\zscan.dat	exists
017gap013.000x-00.50y+00.00\zscan.dat	exists
018gap013.000x+00.00y+00.00\zscan.dat	exists
019gap013.000x+00.50y+00.00\zscan.dat	exists
020gap013.000x+01.00y+00.00\zscan.dat	exists
046gap013.000x+00.00y-00.50\zscan.dat	exists
018gap013.000x+00.00y+00.00\zscan.dat	exists
050gap013.000x+00.00y+00.50\zscan.dat	exists
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022gap016.000x-00.50y+00.00\zscan.dat	exists
023gap016.000x+00.00y+00.00\zscan.dat	exists
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025gap016.000x+01.00y+00.00\zscan.dat	exists
051gap016.000x+00.00y-00.50\zscan.dat	exists
023gap016.000x+00.00y+00.00\zscan.dat	exists
055gap016.000x+00.00y+00.50\zscan.dat	exists
026gap022.000x-01.00y+00.00\zscan.dat	exists
027gap022.000x-00.50y+00.00\zscan.dat	exists
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030gap022.000x+01.00y+00.00\zscan.dat	exists
056gap022.000x+00.00y-00.50\zscan.dat	exists
028gap022.000x+00.00y+00.00\zscan.dat	exists
060gap022.000x+00.00y+00.50\zscan.dat	exists

Sub Folder: Z Scans\On Axis exists

001gap007.200x+00.00y+00.00\zscan.dat	exists
003gap007.500x+00.00y+00.00\zscan.dat	exists
004gap007.750x+00.00y+00.00\zscan.dat	exists
005gap008.000x+00.00y+00.00\zscan.dat	exists
006gap008.250x+00.00y+00.00\zscan.dat	exists
007gap008.500x+00.00y+00.00\zscan.dat	exists
008gap008.750x+00.00y+00.00\zscan.dat	exists



LCLS-II Undulator Segment Measurement Results

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009gap009.000x+00.00y+00.00\zscan.dat	exists
010gap009.250x+00.00y+00.00\zscan.dat	exists
011gap009.500x+00.00y+00.00\zscan.dat	exists
012gap009.750x+00.00y+00.00\zscan.dat	exists
013gap010.000x+00.00y+00.00\zscan.dat	exists
014gap010.250x+00.00y+00.00\zscan.dat	exists
015gap010.500x+00.00y+00.00\zscan.dat	exists
016gap010.750x+00.00y+00.00\zscan.dat	exists
017gap011.000x+00.00y+00.00\zscan.dat	exists
018gap011.500x+00.00y+00.00\zscan.dat	exists
019gap012.000x+00.00y+00.00\zscan.dat	exists
020gap012.500x+00.00y+00.00\zscan.dat	exists
021gap013.000x+00.00y+00.00\zscan.dat	exists
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023gap014.000x+00.00y+00.00\zscan.dat	exists
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026gap015.500x+00.00y+00.00\zscan.dat	exists
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043gap026.000x+00.00y+00.00\zscan.dat	exists
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045gap030.000x+00.00y+00.00\zscan.dat	exists
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LCLS-II Undulator Segment Measurement Results

SXU-003

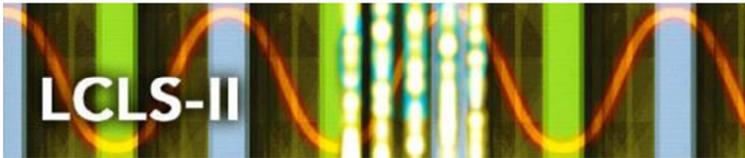
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052gap140.000x+00.00y+00.00\zscan.dat	exists
053gap160.000x+00.00y+00.00\zscan.dat	exists
054gap180.000x+00.00y+00.00\zscan.dat	exists

Sub Folder: Z Scans\Commissioning Gap exists

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Sub Folder: Long Coil\Good Field Region exists

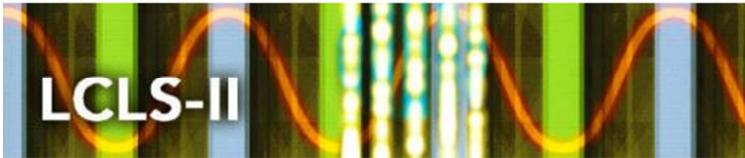
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015gap007.500x+01.00y+00.00_i1x_integrals.txt	exists
031gap007.500x+00.00y-01.00_i1x_integrals.txt	exists
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093gap010.000x+00.00y+00.00_i1x_integrals.txt	exists
094gap010.000x+00.50y+00.00_i1x_integrals.txt	exists
095gap010.000x+01.00y+00.00_i1x_integrals.txt	exists
111gap010.000x+00.00y-01.00_i1x_integrals.txt	exists
115gap010.000x+00.00y+01.00_i1x_integrals.txt	exists
131gap013.000x-01.00y+00.00_i1x_integrals.txt	exists
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LCLS-II Undulator Segment Measurement Results

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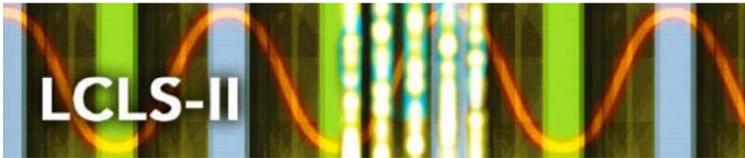
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214gap022.000x+00.50y+00.00_i1x_integrals.txt	exists
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231gap022.000x+00.00y-01.00_i1x_integrals.txt	exists
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040gap007.500x+00.00y+01.00_i2x_integrals.txt	exists
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057gap008.000x-00.50y+00.00_i2x_integrals.txt	exists
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LCLS-II Undulator Segment Measurement Results

SXU-003

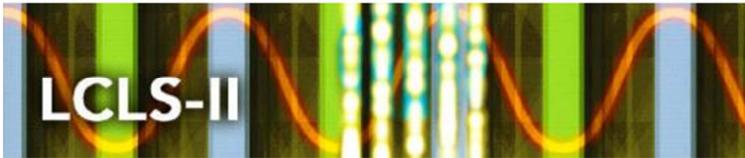
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137gap013.000x-00.50y+00.00_i2x_integrals.txt	exists
138gap013.000x+00.00y+00.00_i2x_integrals.txt	exists
139gap013.000x+00.50y+00.00_i2x_integrals.txt	exists
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177gap016.000x-00.50y+00.00_i2x_integrals.txt	exists
178gap016.000x+00.00y+00.00_i2x_integrals.txt	exists
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180gap016.000x+01.00y+00.00_i2x_integrals.txt	exists
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001gap007.500x-01.00y+00.00_i1y_integrals.txt	exists



LCLS-II Undulator Segment Measurement Results

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003gap007.500x+00.00y+00.00_i1y_integrals.txt	exists
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LCLS-II Undulator Segment Measurement Results

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205gap022.000x+01.00y+00.00_i1y_integrals.txt	exists
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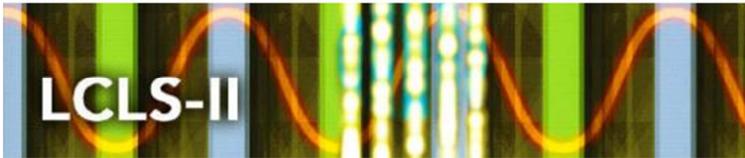
LCLS-II Undulator Segment Measurement Results

SXU-003

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190gap016.000x+00.00y+01.00_i2y_integrals.txt	exists
206gap022.000x-01.00y+00.00_i2y_integrals.txt	exists
207gap022.000x-00.50y+00.00_i2y_integrals.txt	exists
208gap022.000x+00.00y+00.00_i2y_integrals.txt	exists
209gap022.000x+00.50y+00.00_i2y_integrals.txt	exists
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226gap022.000x+00.00y-01.00_i2y_integrals.txt	exists
230gap022.000x+00.00y+01.00_i2y_integrals.txt	exists
246gap100.000x-01.00y+00.00_i2y_integrals.txt	exists
247gap100.000x-00.50y+00.00_i2y_integrals.txt	exists
248gap100.000x+00.00y+00.00_i2y_integrals.txt	exists
249gap100.000x+00.50y+00.00_i2y_integrals.txt	exists
250gap100.000x+01.00y+00.00_i2y_integrals.txt	exists
266gap100.000x+00.00y-01.00_i2y_integrals.txt	exists
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Sub Folder: Long Coil\On Axis exists

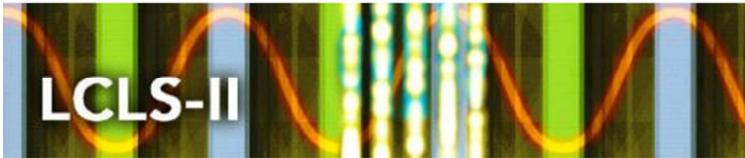
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001gap007.200x+00.00y+00.00_i1y_integrals.txt	exists
002gap007.200x+00.00y+00.00_i2y_integrals.txt	exists
007gap007.500x+00.00y+00.00_i1x_integrals.txt	exists
008gap007.500x+00.00y+00.00_i2x_integrals.txt	exists
005gap007.500x+00.00y+00.00_i1y_integrals.txt	exists
006gap007.500x+00.00y+00.00_i2y_integrals.txt	exists
011gap008.000x+00.00y+00.00_i1x_integrals.txt	exists
012gap008.000x+00.00y+00.00_i2x_integrals.txt	exists
009gap008.000x+00.00y+00.00_i1y_integrals.txt	exists
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LCLS-II Undulator Segment Measurement Results

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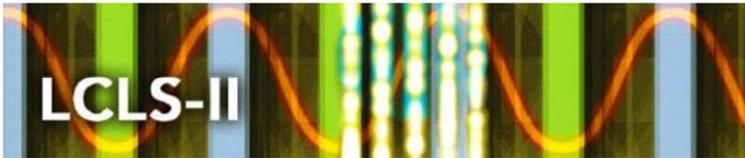
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014gap008.500x+00.00y+00.00_i2y_integrals.txt	exists
019gap009.000x+00.00y+00.00_i1x_integrals.txt	exists
020gap009.000x+00.00y+00.00_i2x_integrals.txt	exists
017gap009.000x+00.00y+00.00_i1y_integrals.txt	exists
018gap009.000x+00.00y+00.00_i2y_integrals.txt	exists
023gap010.000x+00.00y+00.00_i1x_integrals.txt	exists
024gap010.000x+00.00y+00.00_i2x_integrals.txt	exists
021gap010.000x+00.00y+00.00_i1y_integrals.txt	exists
022gap010.000x+00.00y+00.00_i2y_integrals.txt	exists
027gap012.000x+00.00y+00.00_i1x_integrals.txt	exists
028gap012.000x+00.00y+00.00_i2x_integrals.txt	exists
025gap012.000x+00.00y+00.00_i1y_integrals.txt	exists
026gap012.000x+00.00y+00.00_i2y_integrals.txt	exists
031gap014.000x+00.00y+00.00_i1x_integrals.txt	exists
032gap014.000x+00.00y+00.00_i2x_integrals.txt	exists
029gap014.000x+00.00y+00.00_i1y_integrals.txt	exists
030gap014.000x+00.00y+00.00_i2y_integrals.txt	exists
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036gap016.000x+00.00y+00.00_i2x_integrals.txt	exists
033gap016.000x+00.00y+00.00_i1y_integrals.txt	exists
034gap016.000x+00.00y+00.00_i2y_integrals.txt	exists
039gap018.000x+00.00y+00.00_i1x_integrals.txt	exists
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043gap020.000x+00.00y+00.00_i1x_integrals.txt	exists
044gap020.000x+00.00y+00.00_i2x_integrals.txt	exists
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042gap020.000x+00.00y+00.00_i2y_integrals.txt	exists
047gap022.000x+00.00y+00.00_i1x_integrals.txt	exists
048gap022.000x+00.00y+00.00_i2x_integrals.txt	exists
045gap022.000x+00.00y+00.00_i1y_integrals.txt	exists
046gap022.000x+00.00y+00.00_i2y_integrals.txt	exists
051gap025.000x+00.00y+00.00_i1x_integrals.txt	exists
052gap025.000x+00.00y+00.00_i2x_integrals.txt	exists



LCLS-II Undulator Segment Measurement Results

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049gap025.000x+00.00y+00.00_i1y_integrals.txt	exists
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054gap030.000x+00.00y+00.00_i2y_integrals.txt	exists
059gap040.000x+00.00y+00.00_i1x_integrals.txt	exists
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064gap050.000x+00.00y+00.00_i2x_integrals.txt	exists
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067gap060.000x+00.00y+00.00_i1x_integrals.txt	exists
068gap060.000x+00.00y+00.00_i2x_integrals.txt	exists
065gap060.000x+00.00y+00.00_i1y_integrals.txt	exists
066gap060.000x+00.00y+00.00_i2y_integrals.txt	exists
071gap080.000x+00.00y+00.00_i1x_integrals.txt	exists
072gap080.000x+00.00y+00.00_i2x_integrals.txt	exists
069gap080.000x+00.00y+00.00_i1y_integrals.txt	exists
070gap080.000x+00.00y+00.00_i2y_integrals.txt	exists
075gap100.000x+00.00y+00.00_i1x_integrals.txt	exists
076gap100.000x+00.00y+00.00_i2x_integrals.txt	exists
073gap100.000x+00.00y+00.00_i1y_integrals.txt	exists
074gap100.000x+00.00y+00.00_i2y_integrals.txt	exists
079gap120.000x+00.00y+00.00_i1x_integrals.txt	exists
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077gap120.000x+00.00y+00.00_i1y_integrals.txt	exists
078gap120.000x+00.00y+00.00_i2y_integrals.txt	exists
083gap140.000x+00.00y+00.00_i1x_integrals.txt	exists
084gap140.000x+00.00y+00.00_i2x_integrals.txt	exists
081gap140.000x+00.00y+00.00_i1y_integrals.txt	exists
082gap140.000x+00.00y+00.00_i2y_integrals.txt	exists
087gap160.000x+00.00y+00.00_i1x_integrals.txt	exists
088gap160.000x+00.00y+00.00_i2x_integrals.txt	exists
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091gap180.000x+00.00y+00.00_i1x_integrals.txt	exists
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Sub Folder: Fiducialization exists

LCLS2 SXR UND sn003 Fiducial Report.docx	exists
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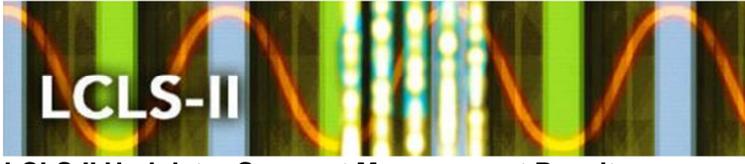
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Sub Folder: Gap Measurements\Touch Probe exists

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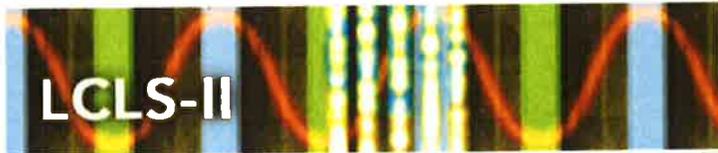
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sxu_003_yctr_vs_gap_spline.dat	exists
sxu_003_i1xvsgap_spline.dat	exists
sxu_003_i1yvsgap_spline.dat	exists
sxu_003_i2xvsgap_spline.dat	exists
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LCLS-II Undulator Segment Measurement Results

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LCLS-II Undulator Segment Measurement Results

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Summary of findings

Finding	Solution
Taper analysis missing	Accepted for now, maybe added later.

Approval and Assignment by Heinz-Dieter Nuhn:

Data Storage Checked:	Y	Y/N
Magnet accepted:	Y	Y/N
Assigned Location	SXU-003	Undulator Name

	Heinz-Dieter Nuhn	11/10/2017
(Signature)	(Name)	(Date)