

LCLS-II Undulator Segment Measurement Results

HXPS-16320

## SLAC Traveler for LCLS-II HXPS Measurement Results

This traveler is intended to document checking the final magnetic measurements of Soft X-Ray beamline (SXR) Phase Shifters (SXPS) performed on the Dover bench in the Magnetic Measurement Facility (MMF) at SLAC after the completion of all tuning activities. It contains basic performance indicators compared against tolerances as well as documentary information both in graphical and textual representation.

Serial number from magnet label:	HXPS-16320
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### Measurement Procedure:

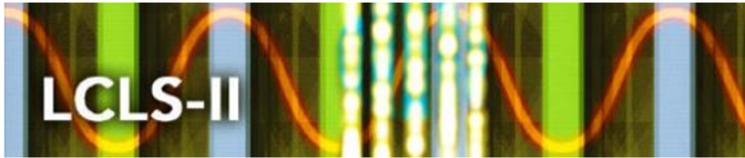
The measurements have been carried out after the undulator segment had been fully tuned according to the “LCLS-II Phase Shifter Test Plan” (LCLS-TN-17-2).

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### Evaluation of Hall Probe Scans: Data Listings A

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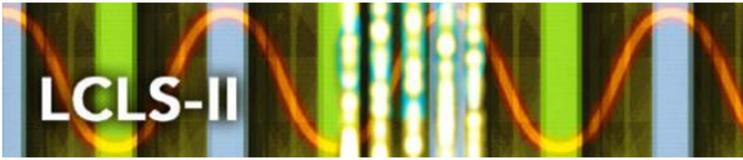
MATLAB function "EvaluatePhaseShifterField" on	04/04/2019 16:40	
A. SCAN PARAMETERS		
Serial Number	HXPS-16320	
z Scanning Date & Time Range	08/15/2018 21:02—08/16/2018 04:50	
Phase Shifter Temperature	20.5969±0.0331	°C
x axis position	0.0307	mm
y axis position	-0.000184	mm
Scans averaged	3	
Nominal Device Length	0.0495	mm
Total Sampling Distance	0.700	mm
Integration Cell Length	0.400	mm
Earth Field Correction $B_x$	-0.100	mm
Earth Field Corection $B_y$	-0.300	mm
Nominal Closed Gap Height	10.000	mm



**Evaluation of Hall Probe Scans: Data Listing B**

MATLAB function "EvaluatePhaseShifterField" on	04/04/2019 16:40	
<b>B. CORE EVALUATIONS FOR CLOSED GAP</b>		
Closed Gap Scanning Date & Time	08/16/2018 01:10	
Closed Gap Temperature	20.66± 0.40	°C
Encoder Gap	9.9995	mm
Encoder Gap Raw	17,811,792	
Measured <i>I1X</i> (Cell Range Total)	-2.86 (14 % of Tolerance)	μTm
Measured <i>I2X</i> (Cell Range Total)	-0.65 (1.4 % of Tolerance)	μTm <sup>2</sup>
Measured <i>I1Y</i> (Cell Range Total)	+3.59 (18 % of Tolerance)	μTm
Measured <i>I2Y</i> (Cell Range Total)	+0.26 (0.53 % of Tolerance)	μTm <sup>2</sup>
Measured <i>PI</i> (Cell Range Total)	697.6	T <sup>2</sup> mm <sup>3</sup>
Required min <i>PI</i> (Cell Range Rotal) at Closed Gap	490.0	T <sup>2</sup> mm <sup>3</sup>
MATLAB function "EvaluatePhaseShifterField" on	04/04/2019 16:40	
<b>C. CORE EVALUATIONS FOR OPEN GAP</b>		
Open Gap Scanning Date & Time	08/16/2018 03:20	
Open Gap Temperature	20.55± 0.40	°C
Encoder Gap	100.0000	mm
Encoder Gap Raw	17,451,790	
Measured <i>I1X</i> (Cell Range Total)	+1.72 (8.6 % of Tolerance)	μTm
Measured <i>I2X</i> (Cell Range Total)	+0.60 (1.3 % of Tolerance)	μTm <sup>2</sup>
Measured <i>I1Y</i> (Cell Range Total)	+3.93 (20 % of Tolerance)	μTm
Measured <i>I2Y</i> (Cell Range Total)	+0.25 (0.51 % of Tolerance)	μTm <sup>2</sup>
Measured <i>PI</i> (Cell Range Total)	0.4	T <sup>2</sup> mm <sup>3</sup>
Required max <i>PI</i> (Cell Range Rotal) at Open Gap	70.0	T <sup>2</sup> mm <sup>3</sup>
MATLAB function "EvaluatePhaseShifterField" on	04/04/2019 16:40	
<b>D. ENCODER SETTINGS</b>		
Gap Encoder Offset	4462.9475	mm

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



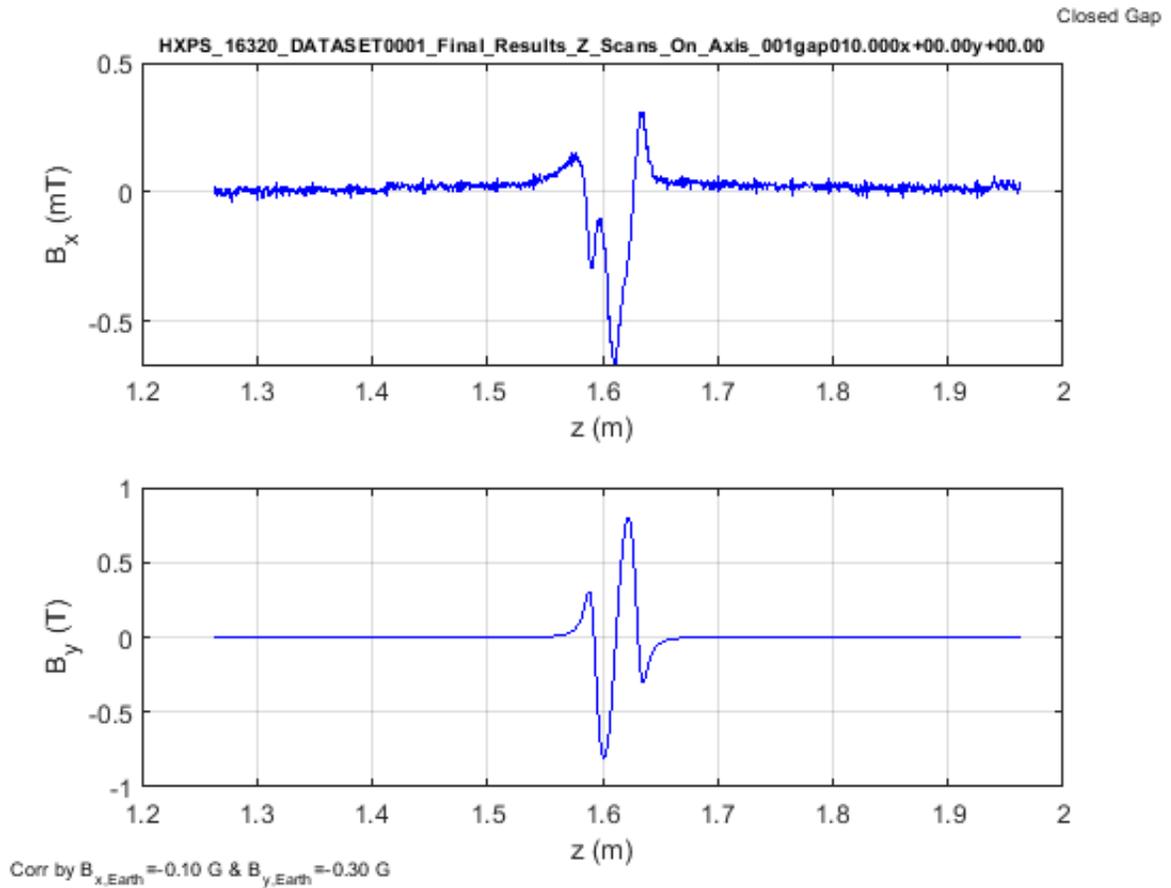
LCLS-II Undulator Segment Measurement Results

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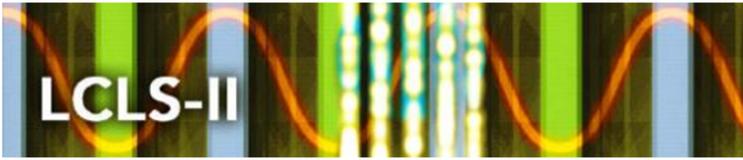
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## Hall Probe Scans at Closed Gap: Horizontal and Vertical Field

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The figures show the  $x$  (upper) and  $y$  (lower) field components along the phase shifter beam axis for the closed gap. The amount of earth field correction applied is shown in the lower left hand side. [Documentary Information]



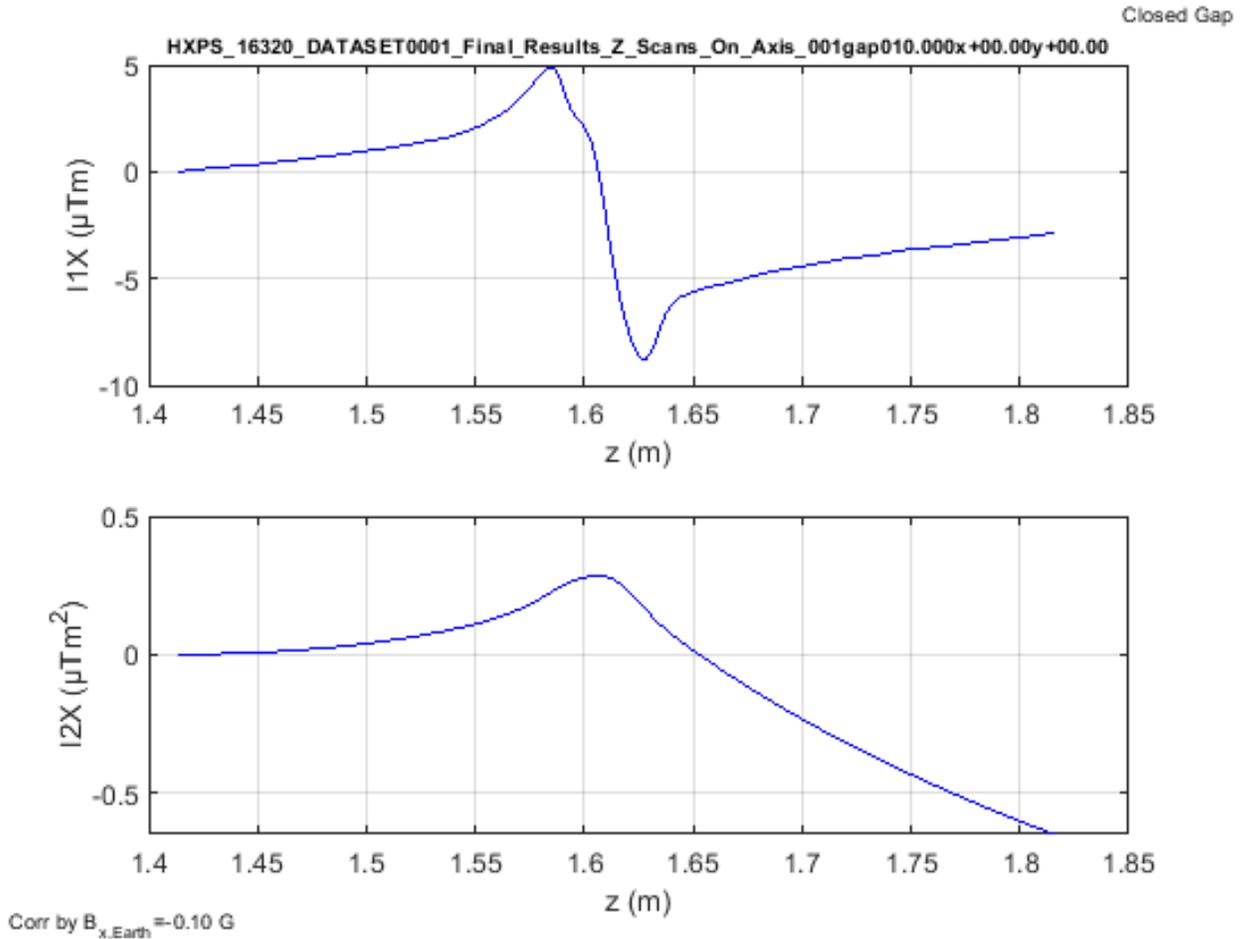
LCLS-II Undulator Segment Measurement Results

HXPS-16320

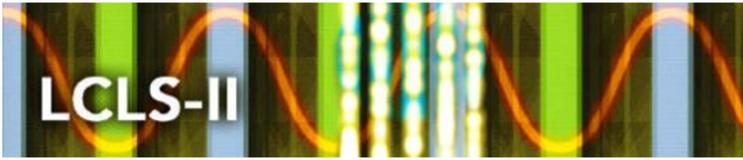
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### Hall Probe Scans at Closed Gap: Horizontal 1<sup>st</sup> and 2<sup>nd</sup> Field Integrals

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The figures show the horizontal first (I1X, upper) and second (I2X, lower) field integrals along the phase shifter beam axis for the closed gap. The amount of earth field correction applied is shown in the lower left hand side. [Documentary Information]



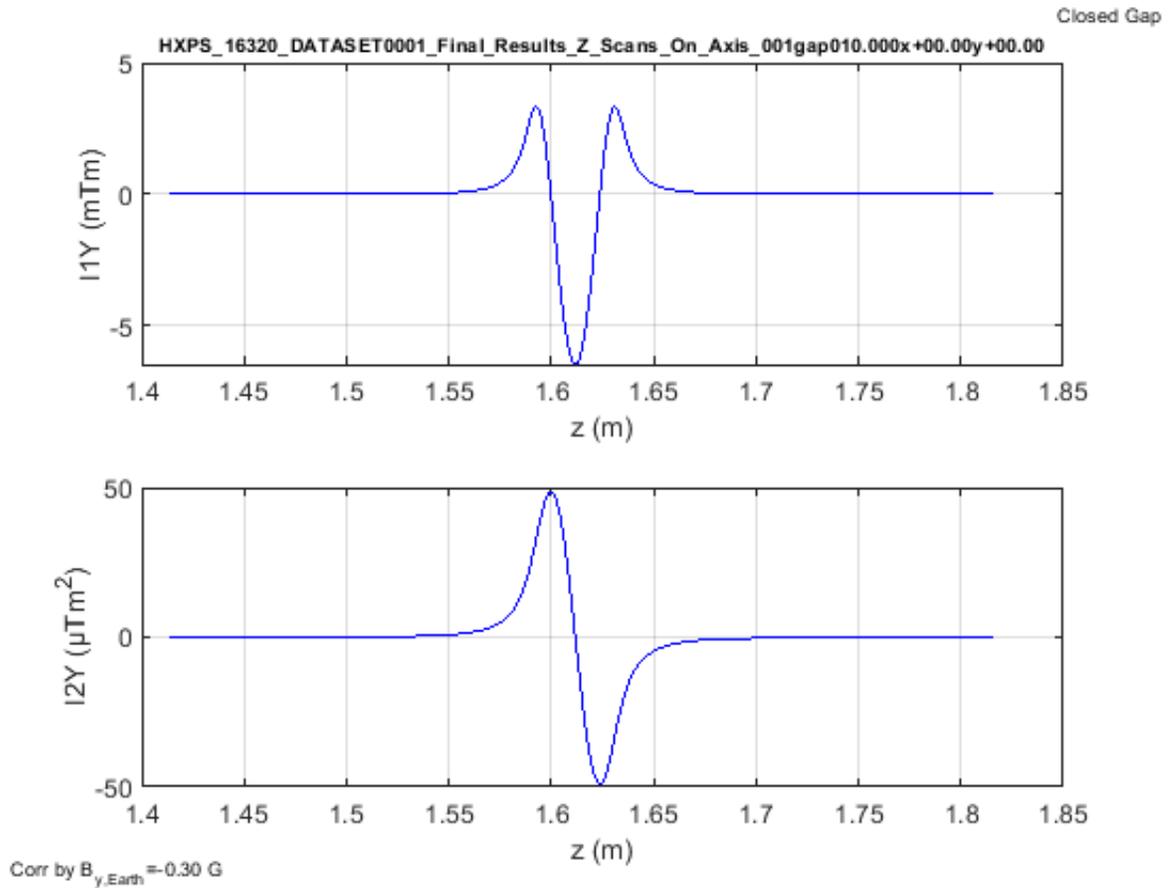
LCLS-II Undulator Segment Measurement Results

HXPS-16320

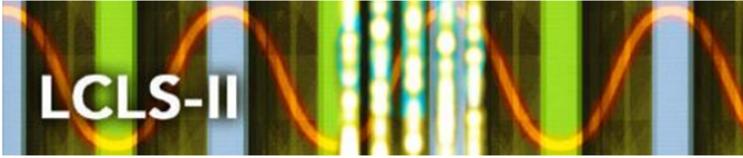
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## Hall Probe Scans at Closed Gap: Vertical 1<sup>st</sup> and 2<sup>nd</sup> Field Integrals

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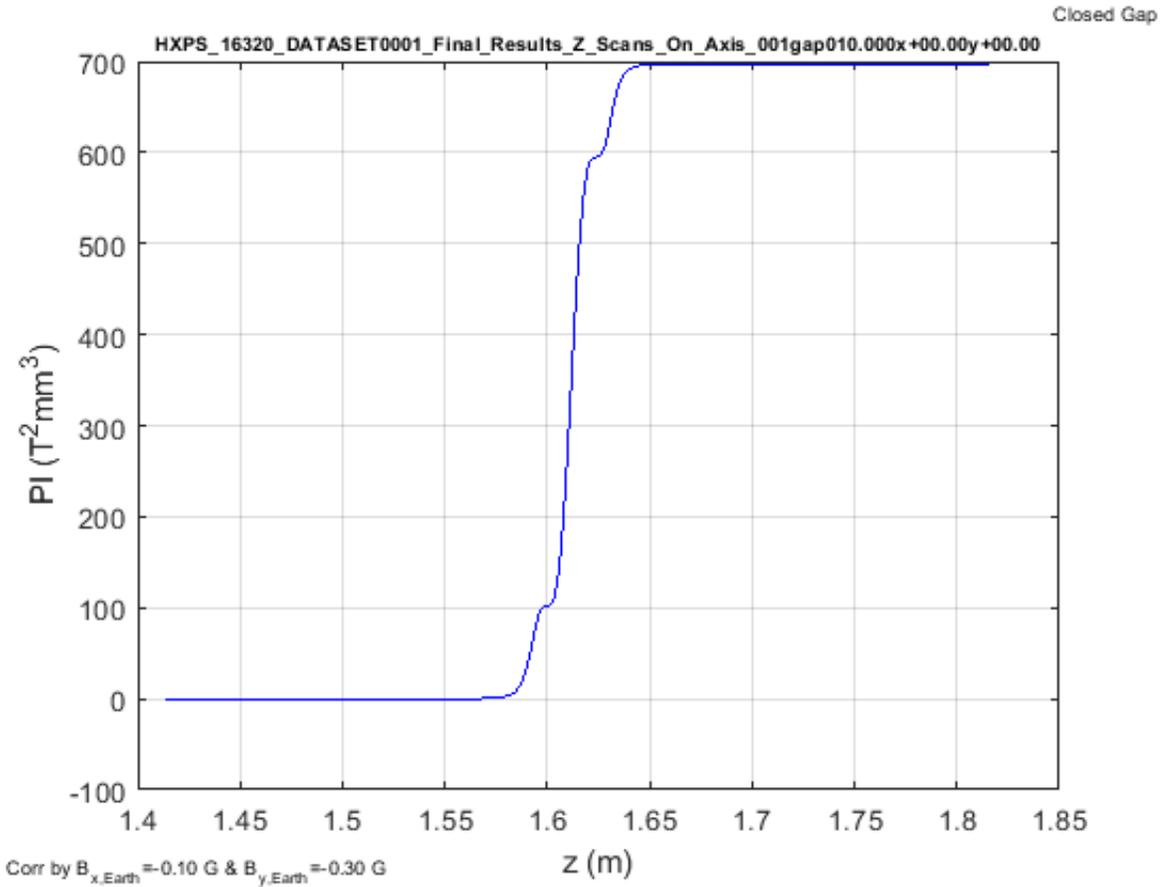
The figures show the vertical first (I1Y, upper) and second (I2Y, lower) field integrals along the phase shifter beam axis for the closed gap. The amount of earth field correction applied is shown in the lower left hand side. [Documentary Information]



LCLS-II Undulator Segment Measurement Results

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## Evaluation of Hall Probe Scans for Closed Gap: Phase Integral Plot



The figure shows the phase integral,  $PI$ , of an electron calculated from the measured on-axis magnetic field components for the closed gap:

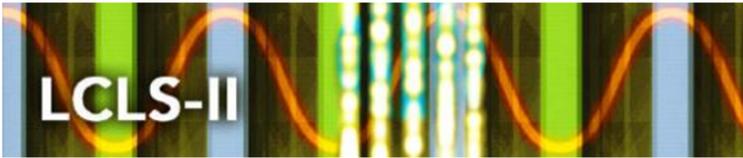
$$PI(z) = \int_0^z BL_{x1}^2(\hat{z}) d\hat{z} + \int_0^z BL_{y1}^2(\hat{z}) d\hat{z}$$

with

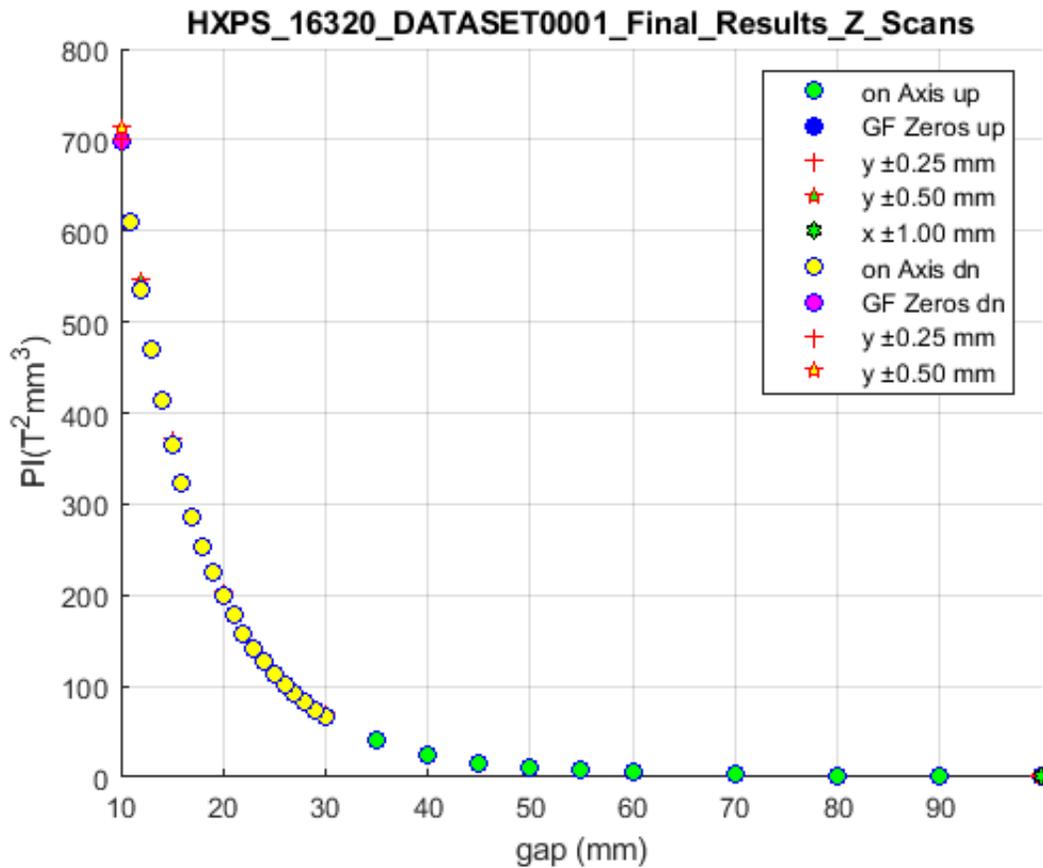
$$BL_{x1,y1}(z) = \int_0^z B_{x,y}(\hat{z}) d\hat{z}.$$

The phase integral is proportional to the phase slippage due to the presence of the magnetic field. There is an additional contribution to phase slippage due to the fact that the speed of the electrons is less than the speed of light. This additional contribution is corrected by the undulator segment and does not need to be corrected again for the phase shifters.

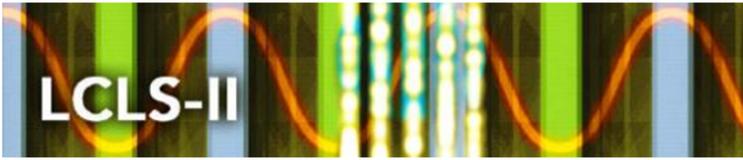
The following figures show the results of the gap dependent analysis.



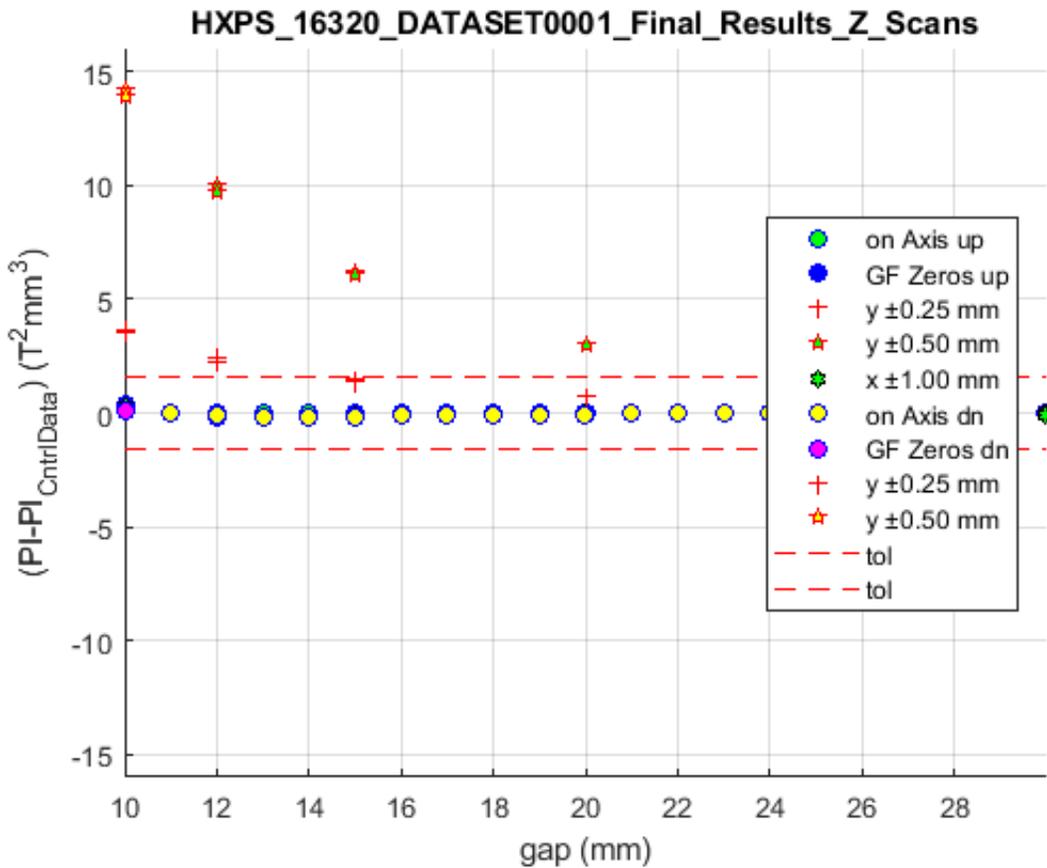
Evaluation of Hall Probe Scans: *PI* vs. *gap*



The figure shows phase shifter Phase Integral,  $PI$ , as a function of gap over the 10 mm—90 mm gap 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 gap encoder installed on the SXPS. In that sense these are nominal gap numbers that will be close but not identical to each of the individual magnet block separations measured across the phase shifter gap. The continuous conversion between the two axes (i.e.,  $PI(gap)$  and  $gap(PI)$ ) will be done during operations based on the list of reference data points stored in file `hxps_16320_pivsgap_spline.dat` in the Controls Data folder on the V: drive (see final section of this document for file information). From that  $PI(gap)$  and  $gap(PI)$  can be calculated via cubic spline fits or equivalent. [Documentary Information]

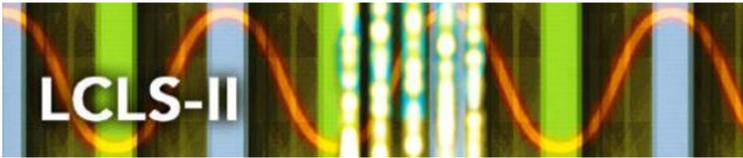


Evaluation of Hall Scans:  $PI - PI_{\text{control}}$  vs.  $gap$

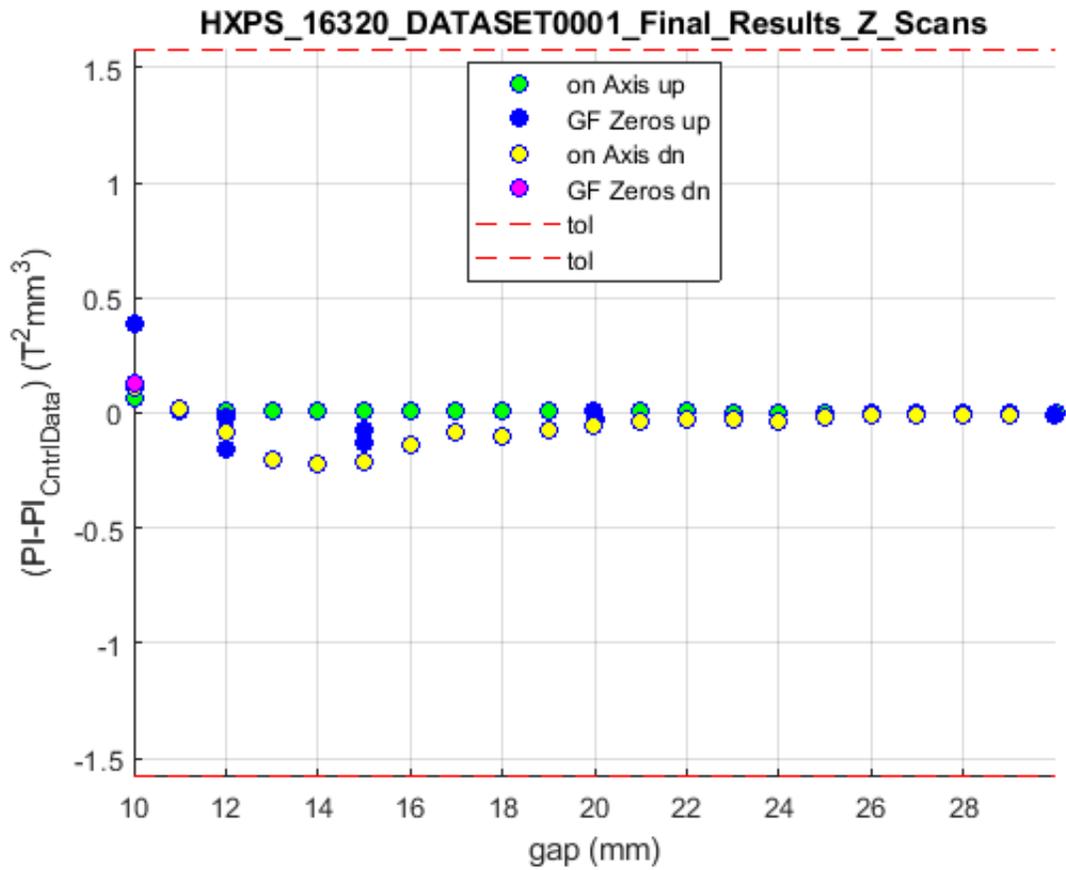


The figure shows the relative difference between the measured phase shifter Phase Integral,  $PI$ , and a cubic spline fit to the list of reference data points as a function of gap over the 10 mm–30 mm operational range. The cubic spline fit data is stored on the V: drive in the Controls Data folder in file `hxps_16320_pivsgap_spline`.

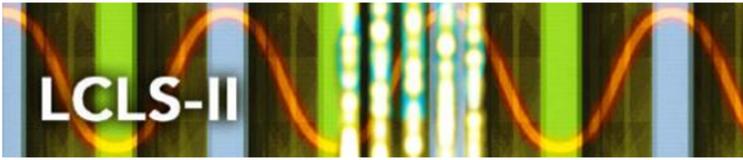
The legend explains the different cases that are shown in the plot: The data show as green filled circles have been acquired on axis as the gap was changed from closed to open. The yellow filled circles show data acquired on axis as the gap was changed from open to closed. The horizontal red dashed lines show the tolerance limits. The other symbols shown indicate off-axis measurements that are added for interest only. The tolerance limits apply for on-axis readings, only.



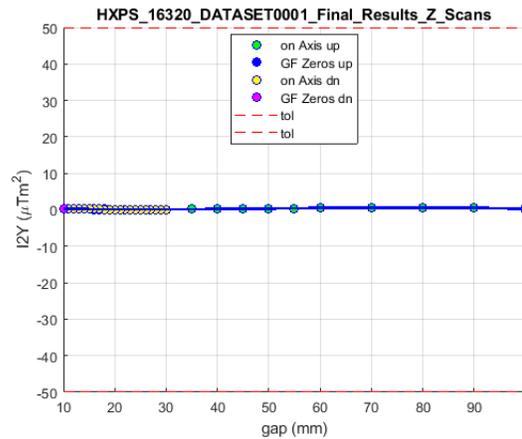
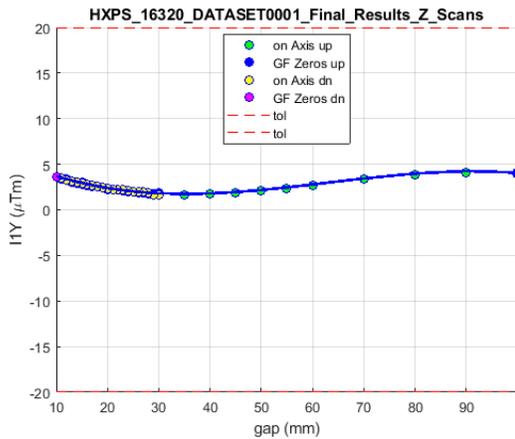
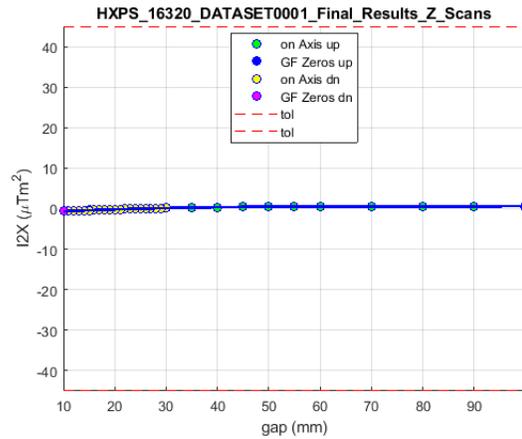
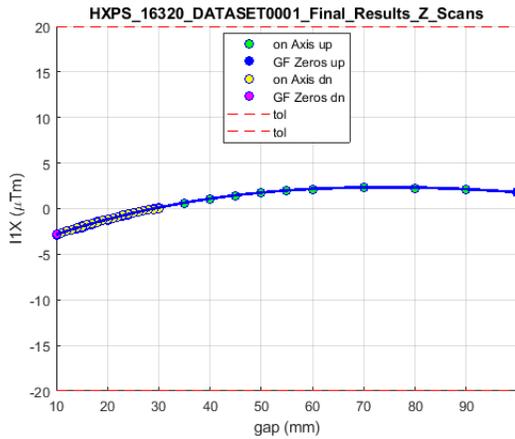
Evaluation of Hall Scans:  $PI - PI_{control}$  vs.  $gap$



The figure shows some of the data shown in the previous figure but with a larger vertical scale that just captures the tolerance range. There is a hysteresis effect visible which is small enough to be acceptable. The off-axis measurements are not shown.



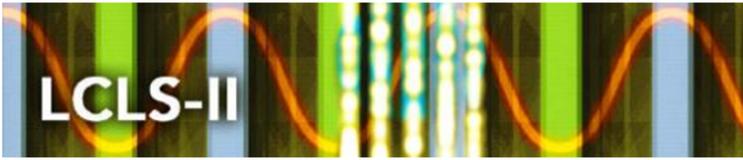
## Evaluation of Hall Probe: Field Integrals vs. gap



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

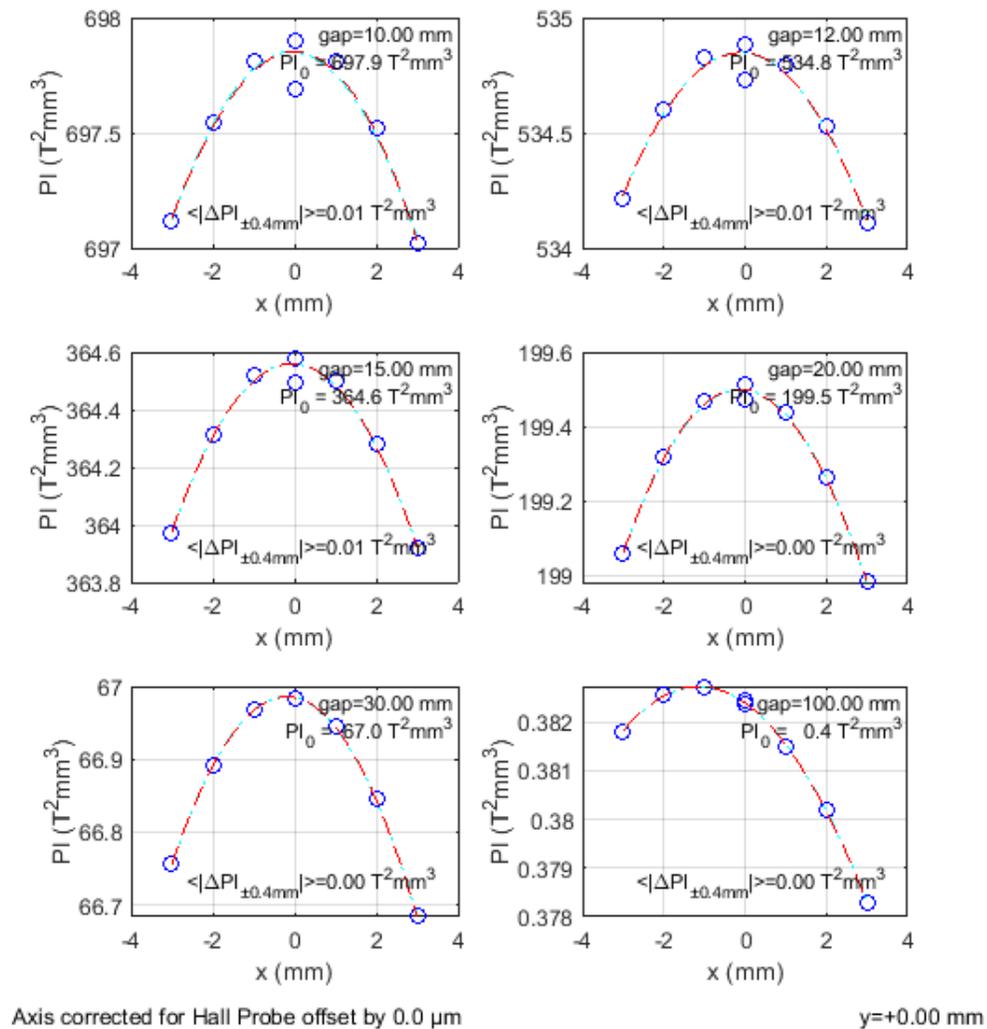
```
“...i1x_vs_gap_spline.dat”,  
“...i2x_vs_gap_spline.dat”,  
“...i1y_vs_gap_spline.dat”,  
“...i2y_vs_gap_spline.dat”,
```

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

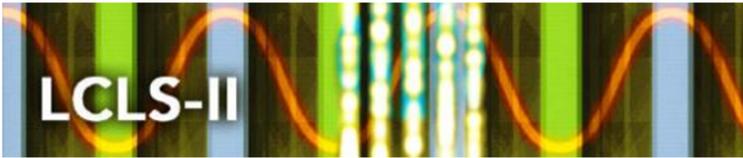


Evaluation of Hall Scans:  $PI$  vs.  $x$  dependence

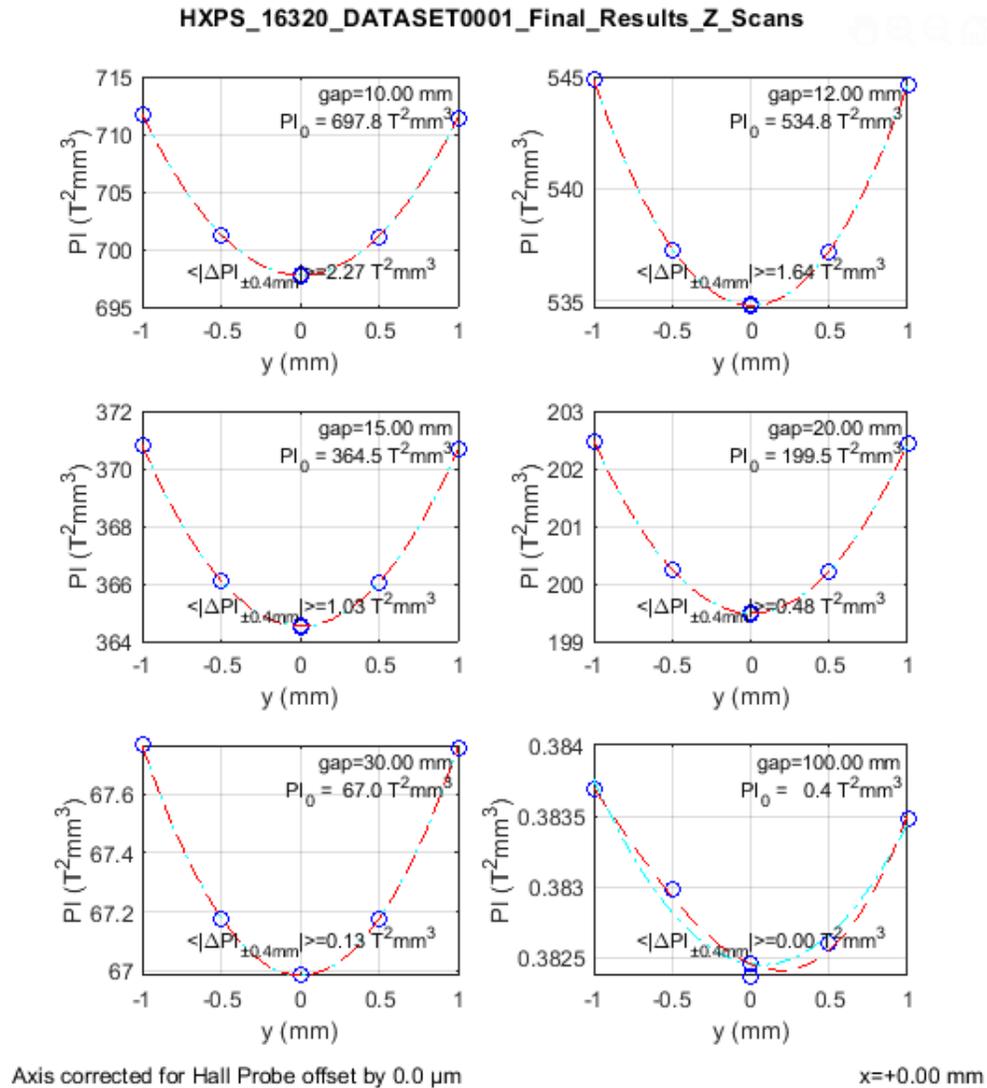
HXPS\_16320\_DATASET0001\_Final\_Results\_Z\_Scans



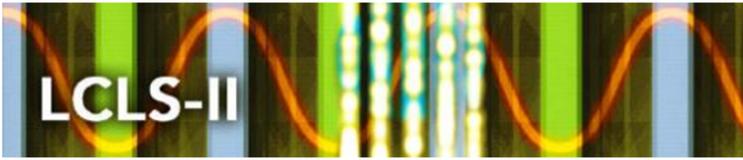
The figure shows the deviation of the phase integral,  $PI$ , from the off-axis value,  $PI_0$ , as function of  $x$  at a number of operational gaps. The average deviation at  $z = \pm 0.4$  mm is printed at the lower part of each plot. [Documentary Information]



Evaluation of Hall Scans:  $PI$  vs.  $y$  dependence



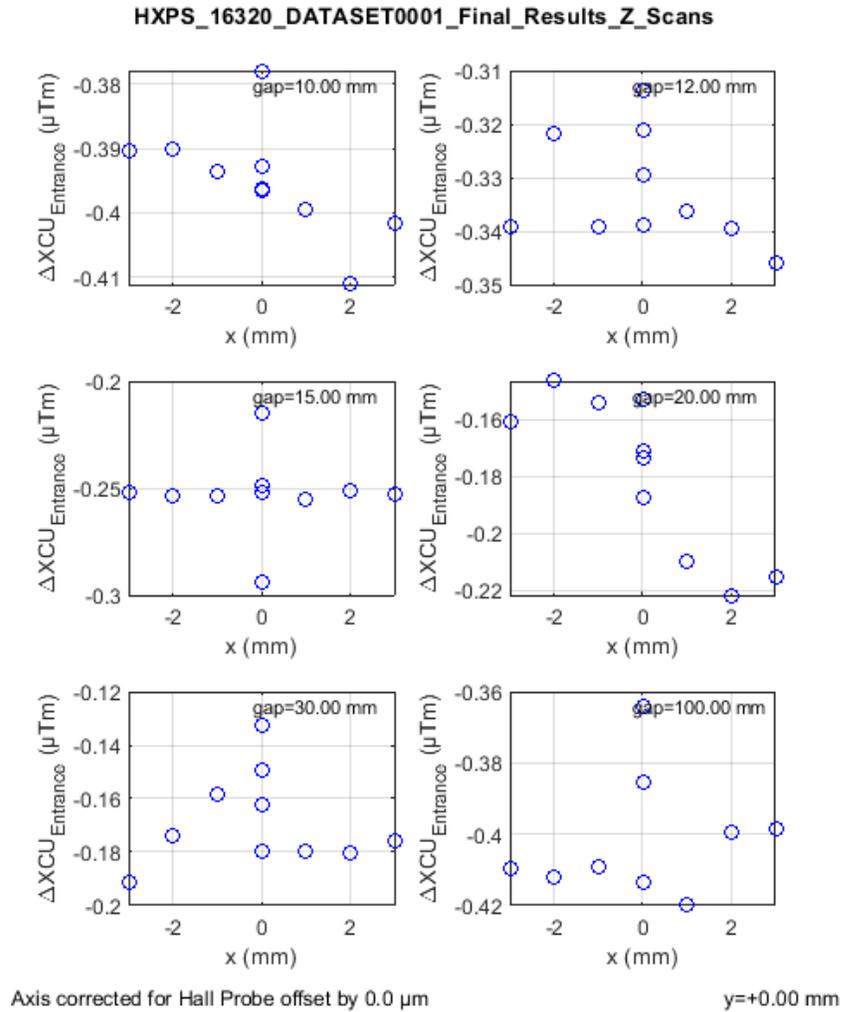
The figure shows the deviation of the phase integral,  $PI$ , value from the on-axis value,  $PI_0$ , as function of  $y$  at a number of operational gaps. The average deviation at  $z = \pm 0.4$  mm is printed at the lower part of each plot. [Documentary Information]



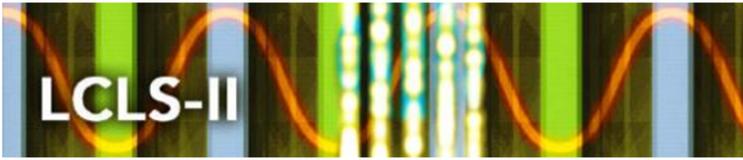
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### Estimated Upstream Horizontal Corrector Strength Requirement vs. $x$

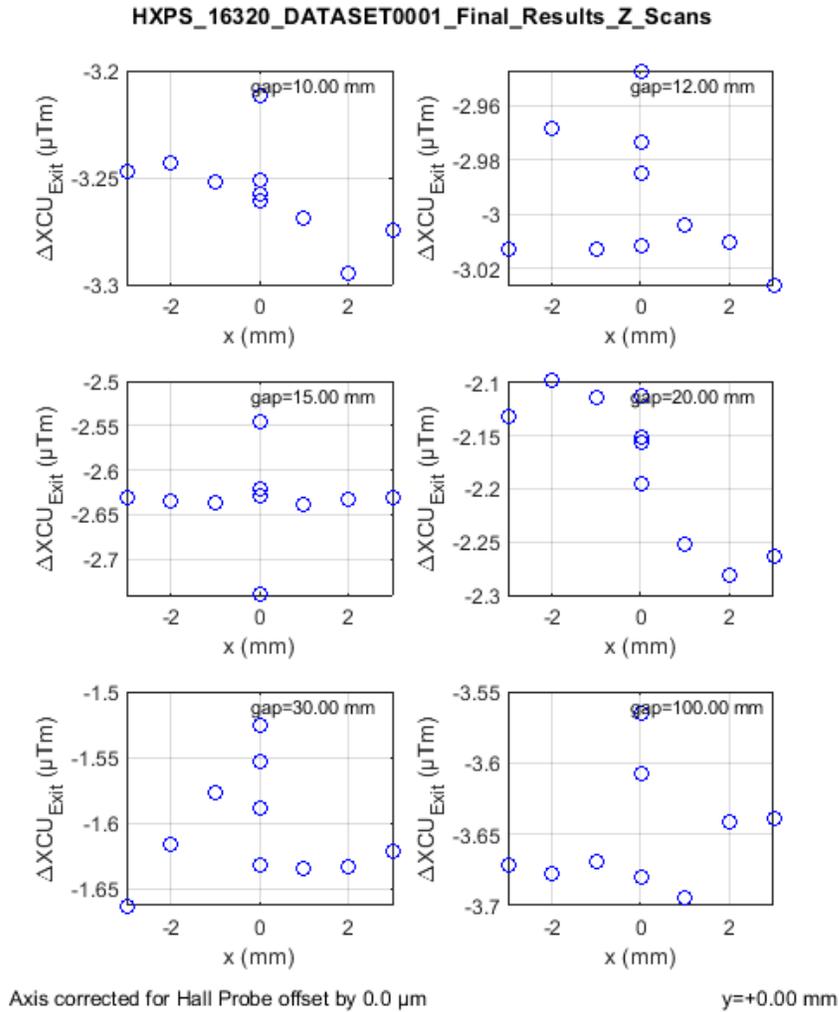
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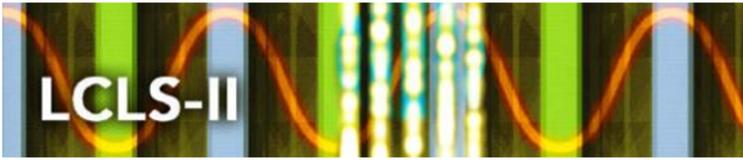
The figure shows the required strength of the upstream horizontal corrector to remove the second vertical phase shifter field integral at the downstream BPM for a number of phase shifter gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very small.



### Estimated Downstream Horizontal Corrector Strength Requirement vs. $x$



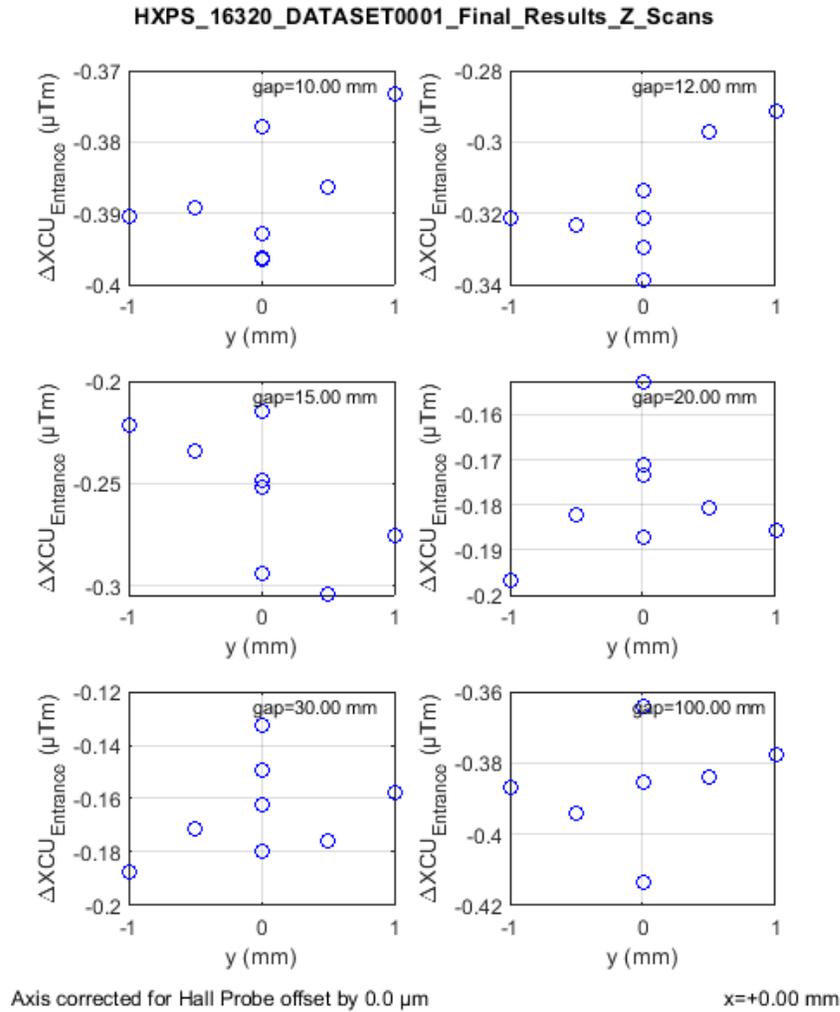
The figure shows the required strength of the downstream horizontal corrector to remove the first vertical phase shifter field integral and upstream corrector field integral at the downstream BPM for a number of operational phase shifter gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very.



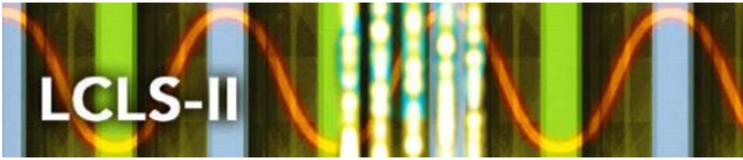
LCLS-II Undulator Segment Measurement Results

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### Estimated Upstream Horizontal Corrector Strength Requirement vs. $y$



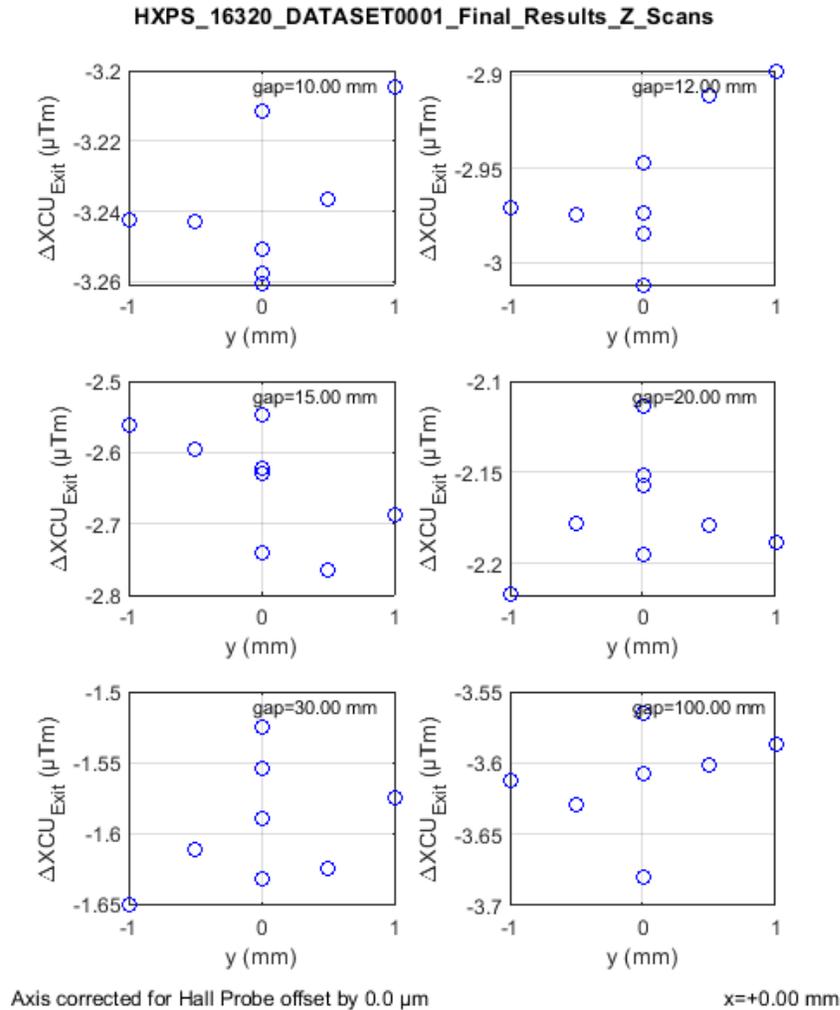
The figure shows the required strength of the upstream horizontal corrector to remove the second vertical phase shifter field integral at the downstream BPM for a number of operational phase shifter gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very small.



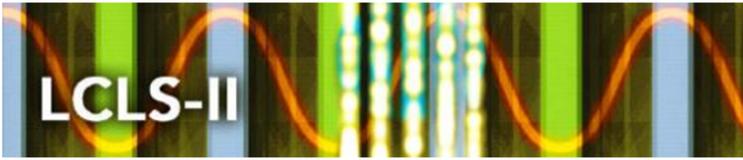
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**Estimated Downstream Horizontal Corrector Strength Requirement vs.  $y$**

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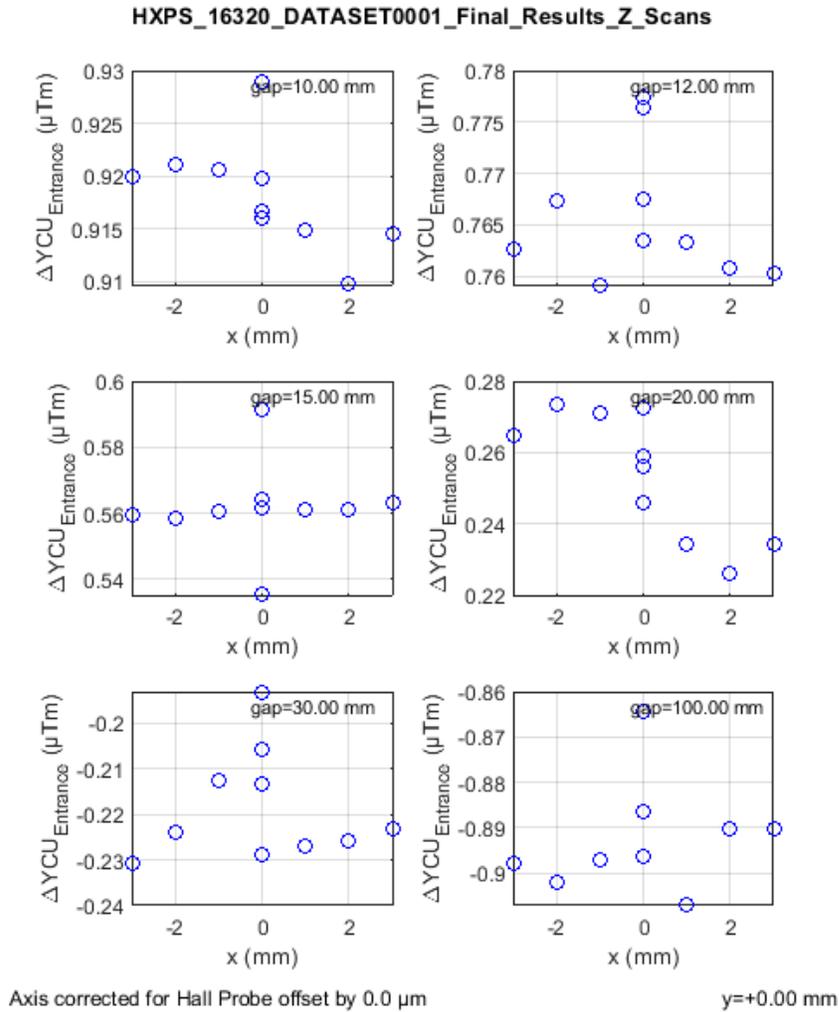
The figure shows the required strength of the upstream horizontal corrector to remove the first vertical phase shifter and upstream corrector field integral at the downstream BPM for a number of operational undulator gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very small.



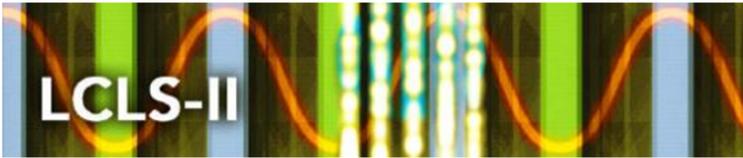
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### Estimated Upstream Vertical Corrector Strength Requirement vs. $x$

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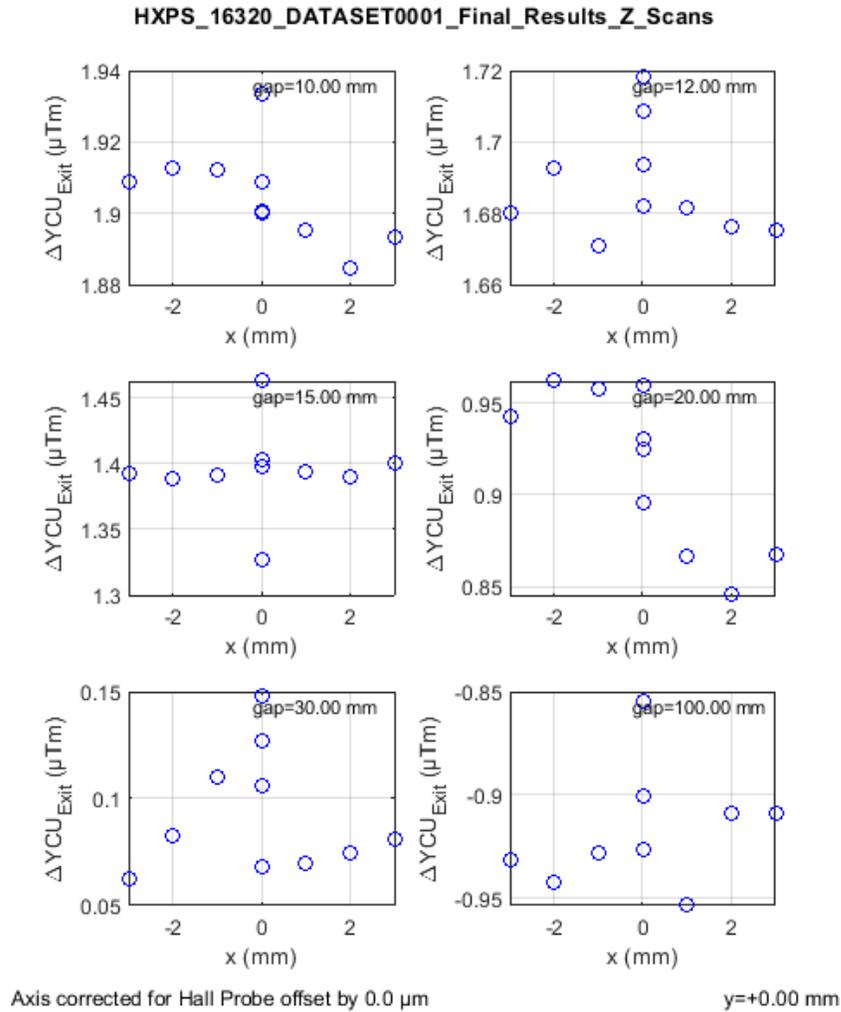
The figure shows the required strength of the upstream horizontal corrector to remove the second horizontal phase shifter field integral at the downstream BPM for a number of operational phase shifter gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very small.



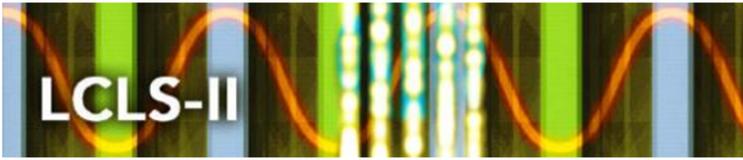
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**Estimated Downstream Vertical Corrector Strength Requirement vs.  $x$**

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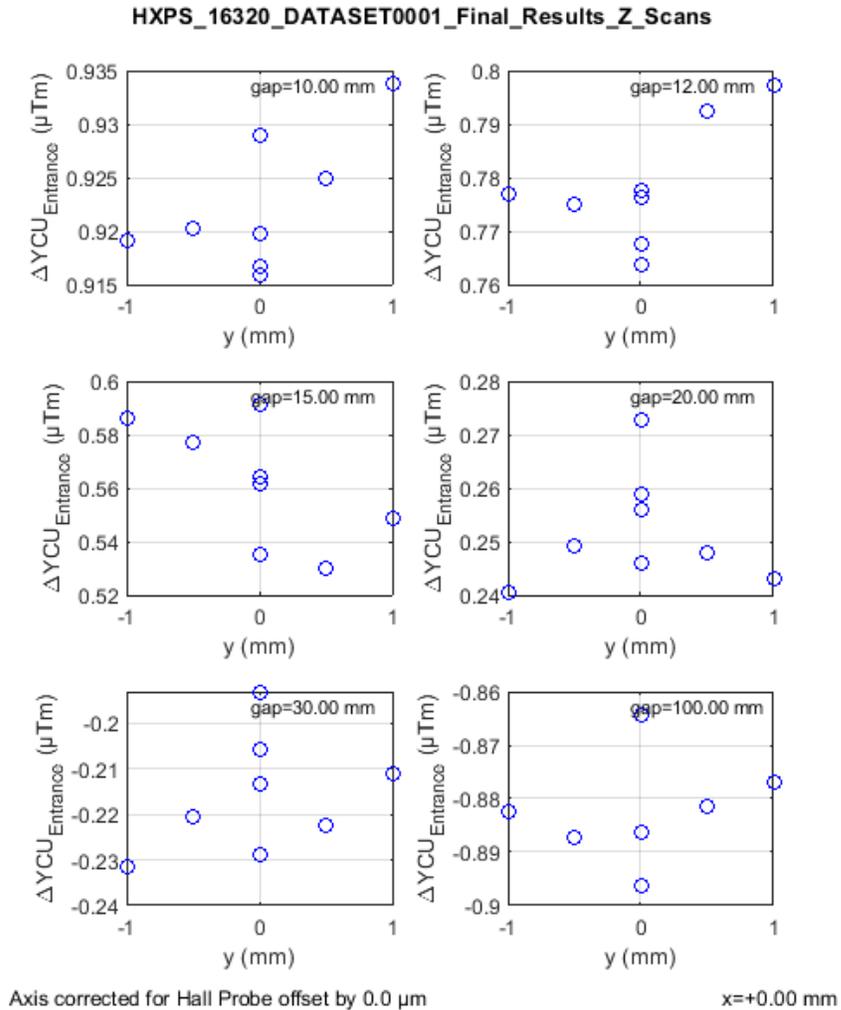
The figure shows the required strength of the downstream vertical corrector to remove the first horizontal phase shifter field integral and upstream corrector fields integral at the downstream BPM for a number of operational phase shifter gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very small.



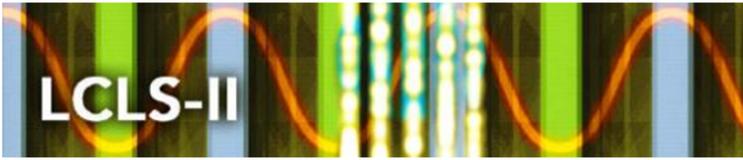
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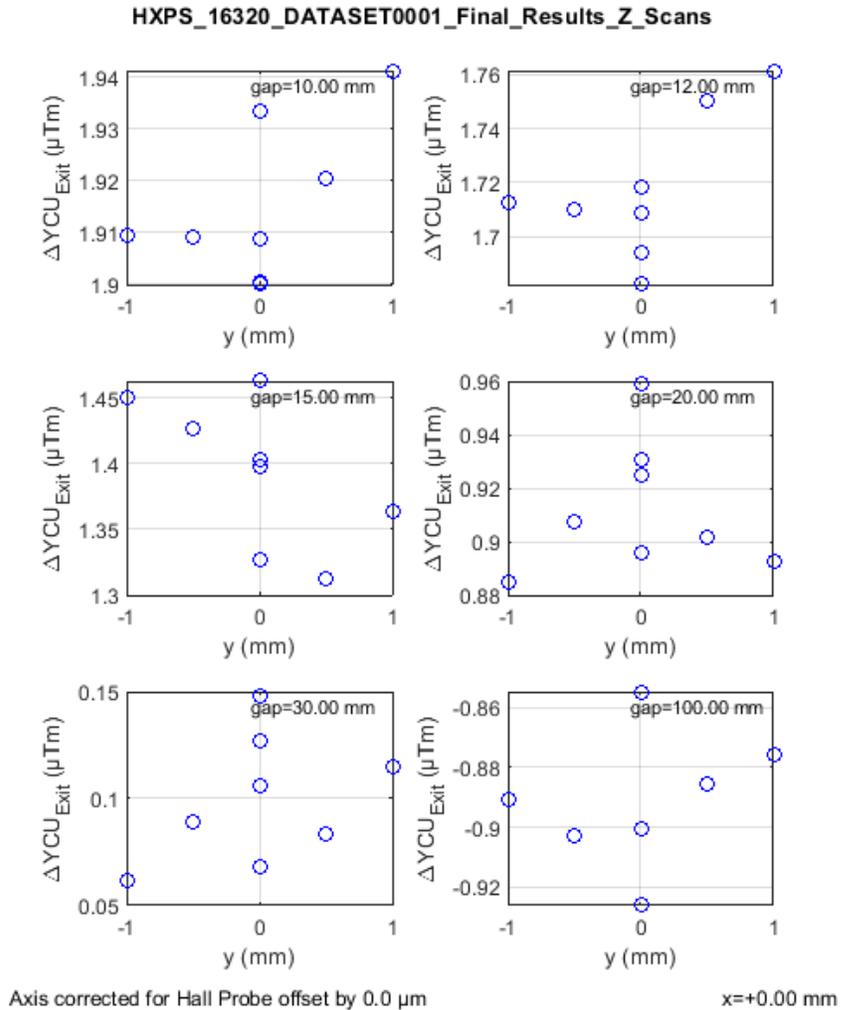
### Estimated Upstream Vertical Corrector Strength Requirement vs. $y$



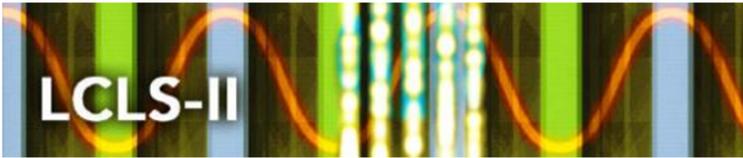
The figure shows the required strength of the upstream vertical corrector to remove the second horizontal phase shifter field integral at the downstream BPM for a number of operational phase shifter gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very small.



### Estimated Upstream Vertical Corrector Strength Requirement vs. $y$



The figure shows the required strength of the downstream vertical corrector to remove the first horizontal phase shifter field integral and the upstream corrector fields integral at the downstream BPM for a number of operational phase shifter gaps. The analysis was done at a number of off-axis locations in the  $x-z$  plane. All values are very small.



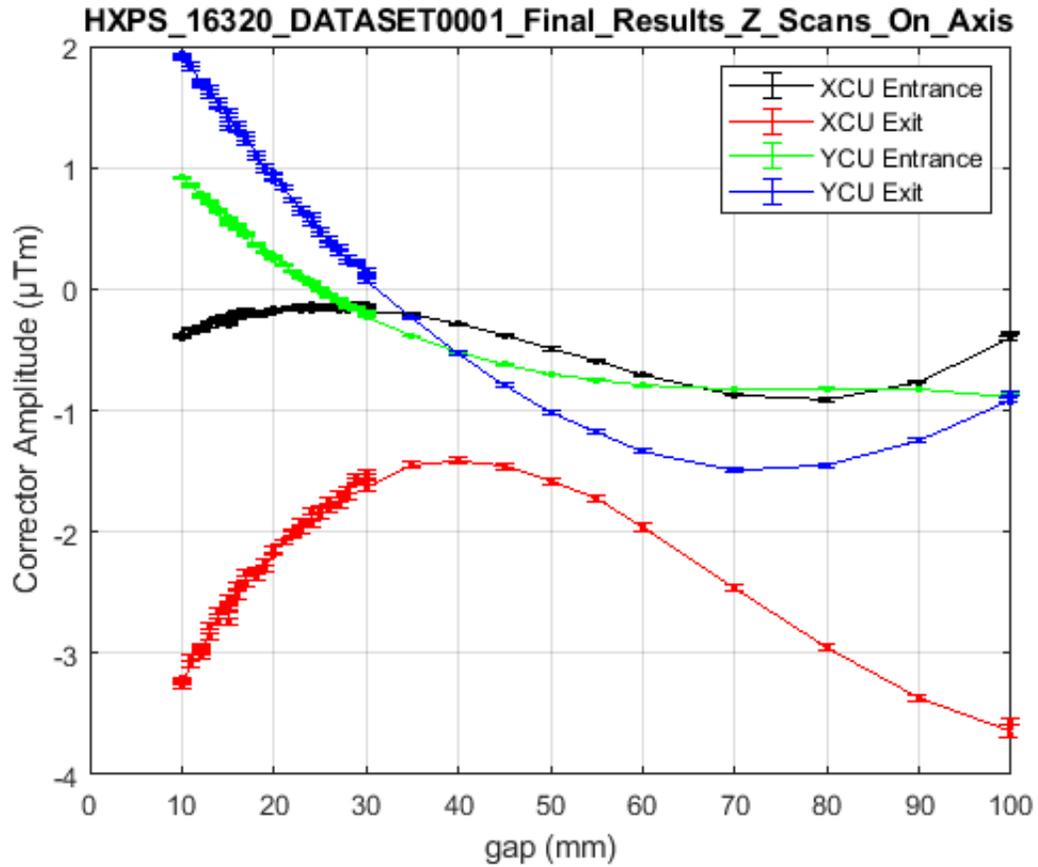
LCLS-II Undulator Segment Measurement Results

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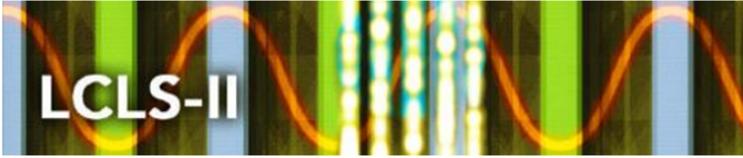
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### Estimated Corrector Strengths Requirement vs. gap

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The figure shows as a function of phase shifter 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 very small.



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## Measurement Results are stored:

### At V-Drive:

V:\MET\MagServe\MagData\LCLS-II\Phase Shifter\  
 \_\_\_\_\_

### In Folder

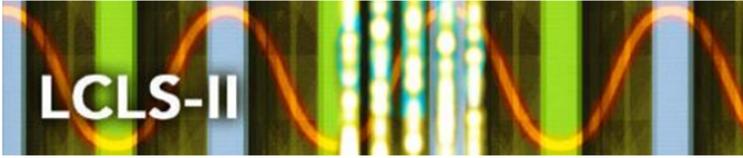
HXPS\_16320\DATASET0001\MagServe\Final Results\  
 \_\_\_\_\_

## Confirmation of File Locations:

The following tables list 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

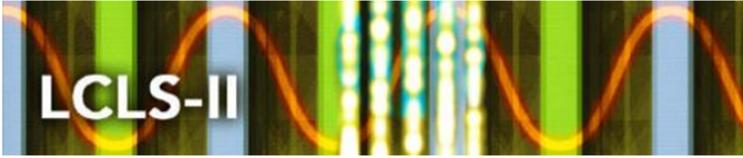
001gap010.000x-03.00y+00.00\zscan.dat	exists
002gap010.000x-02.00y+00.00\zscan.dat	exists
003gap010.000x-01.00y+00.00\zscan.dat	exists
004gap010.000x+00.00y+00.00\zscan.dat	exists
005gap010.000x+01.00y+00.00\zscan.dat	exists
006gap010.000x+02.00y+00.00\zscan.dat	exists
007gap010.000x+03.00y+00.00\zscan.dat	exists
044gap010.000x+00.00y-00.50\zscan.dat	exists
004gap010.000x+00.00y+00.00\zscan.dat	exists
046gap010.000x+00.00y+00.50\zscan.dat	exists
008gap012.000x-03.00y+00.00\zscan.dat	exists
009gap012.000x-02.00y+00.00\zscan.dat	exists
010gap012.000x-01.00y+00.00\zscan.dat	exists
011gap012.000x+00.00y+00.00\zscan.dat	exists
012gap012.000x+01.00y+00.00\zscan.dat	exists
013gap012.000x+02.00y+00.00\zscan.dat	exists
014gap012.000x+03.00y+00.00\zscan.dat	exists
049gap012.000x+00.00y-00.50\zscan.dat	exists
011gap012.000x+00.00y+00.00\zscan.dat	exists



LCLS-II Undulator Segment Measurement Results

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051gap012.000x+00.00y+00.50\zscan.dat	exists
015gap015.000x-03.00y+00.00\zscan.dat	exists
016gap015.000x-02.00y+00.00\zscan.dat	exists
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023gap020.000x-02.00y+00.00\zscan.dat	exists
024gap020.000x-01.00y+00.00\zscan.dat	exists
025gap020.000x+00.00y+00.00\zscan.dat	exists
026gap020.000x+01.00y+00.00\zscan.dat	exists
027gap020.000x+02.00y+00.00\zscan.dat	exists
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059gap020.000x+00.00y-00.50\zscan.dat	exists
025gap020.000x+00.00y+00.00\zscan.dat	exists
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029gap030.000x-03.00y+00.00\zscan.dat	exists
030gap030.000x-02.00y+00.00\zscan.dat	exists
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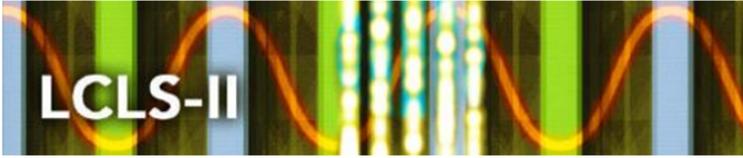
LCLS-II Undulator Segment Measurement Results

HXPS-16320

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039gap100.000x+00.00y+00.00\zscan.dat	exists
071gap100.000x+00.00y+00.50\zscan.dat	exists

Sub folder: Z Scans\On Axis exists

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LCLS-II Undulator Segment Measurement Results

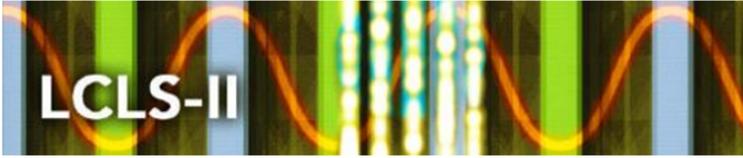
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Sub folder: Stretched Wire exists

Sub folder: Stretched Wire\Good Field Region exists

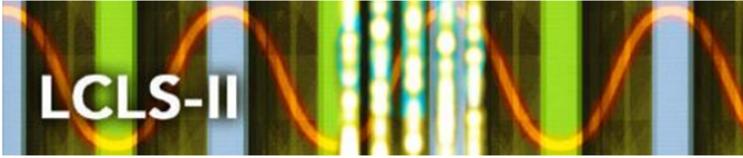
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LCLS-II Undulator Segment Measurement Results

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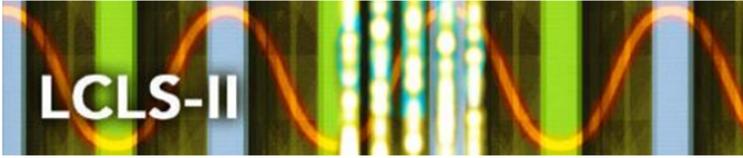
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LCLS-II Undulator Segment Measurement Results

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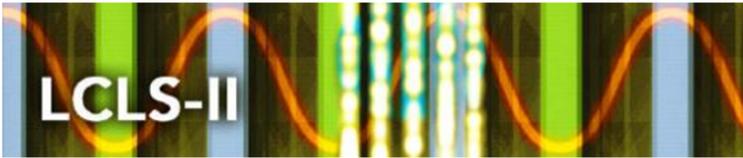
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LCLS-II Undulator Segment Measurement Results

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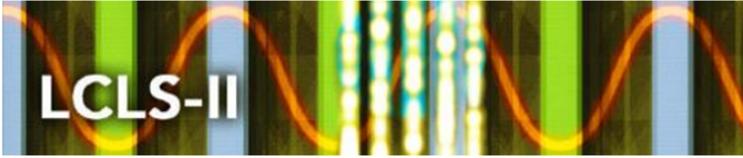
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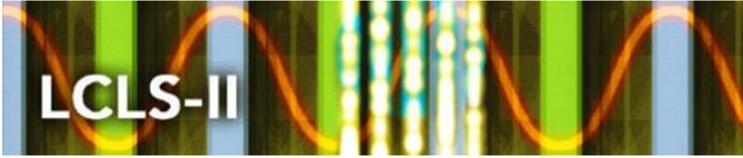
LCLS-II Undulator Segment Measurement Results

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069gap012.000x+00.00y+01.00.i2Y_integrals.txt	exists
070gap012.000x+00.00y+02.00.i2Y_integrals.txt	exists
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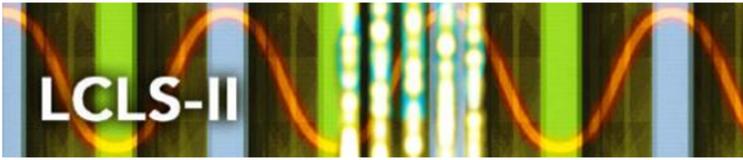
LCLS-II Undulator Segment Measurement Results

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186gap030.000x+00.00y-02.00.i2Y_integrals.txt	exists
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190gap030.000x+00.00y+02.00.i2Y_integrals.txt	exists
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227gap100.000x+00.00y-01.00.i2Y_integrals.txt	exists
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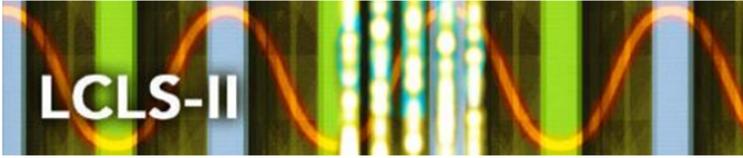
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LCLS-II Undulator Segment Measurement Results

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035gap026.000x+00.00y+00.00.i1X_integrals.txt	exists
039gap028.000x+00.00y+00.00.i1X_integrals.txt	exists
043gap030.000x+00.00y+00.00.i1X_integrals.txt	exists
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076gap100.000x+00.00y+00.00.i2X_integrals.txt	exists
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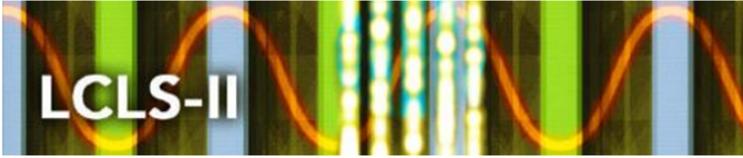


LCLS-II Undulator Segment Measurement Results

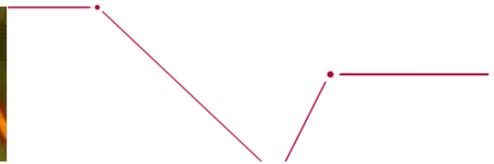
HXPS-16320

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050gap040.000x+00.00y+00.00.i2Y_integrals.txt	exists
054gap050.000x+00.00y+00.00.i2Y_integrals.txt	exists
058gap060.000x+00.00y+00.00.i2Y_integrals.txt	exists
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066gap080.000x+00.00y+00.00.i2Y_integrals.txt	exists
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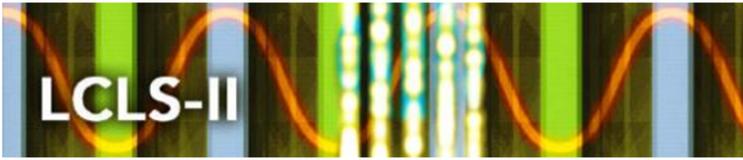


LCLS-II Undulator Segment Measurement Results

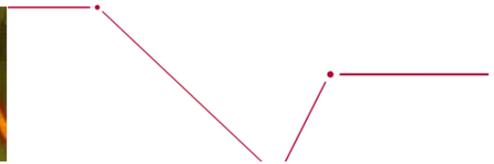


HXPS-16320

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LCLS-II Undulator Segment Measurement Results



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Summary of findings

Finding	Solution

Approval and Assignment by Heinz-Dieter Nuhn

Data Storage Checked:	Y	
Magnet Accepted:	Y	
Assigned Location:	HXPS-16320	

	Heinz-Dieter Nuhn	April 4, 2019
(Signature)	(Name)	(Date)