Study on the discrepancy between the prediction from magnetic measurement and the result from beam based measurement/spectral measurement for NSLS-II IDs

Toshi Tanabe

Energy and Photon Sciences Directorate,

Brookhaven National Laboratory, Upton NY 11973

Outline

- NSLS-II Storage Ring and Science Programs
- NSLS-II Insertion Devices
  - List of IDs, Installation History, etc.
  - NSLS-II ID-Magnetic Measurement Facility (ID-MMF)
  - Spectrum based ID alignment
  - 1st Integral comparison between mag. meas. and beam based one
  - Multipole Measurement / Skew quadrupole issue
- Summary

Acknowledgement:

ID group members: C. Kitegi (now at Soleil), D. Hidas, M. Musardo, J. Rank, D.A. Harder, P. Cappadoro, H. Fernandes, T. Corwin, C. Rhein and B. Licciardi

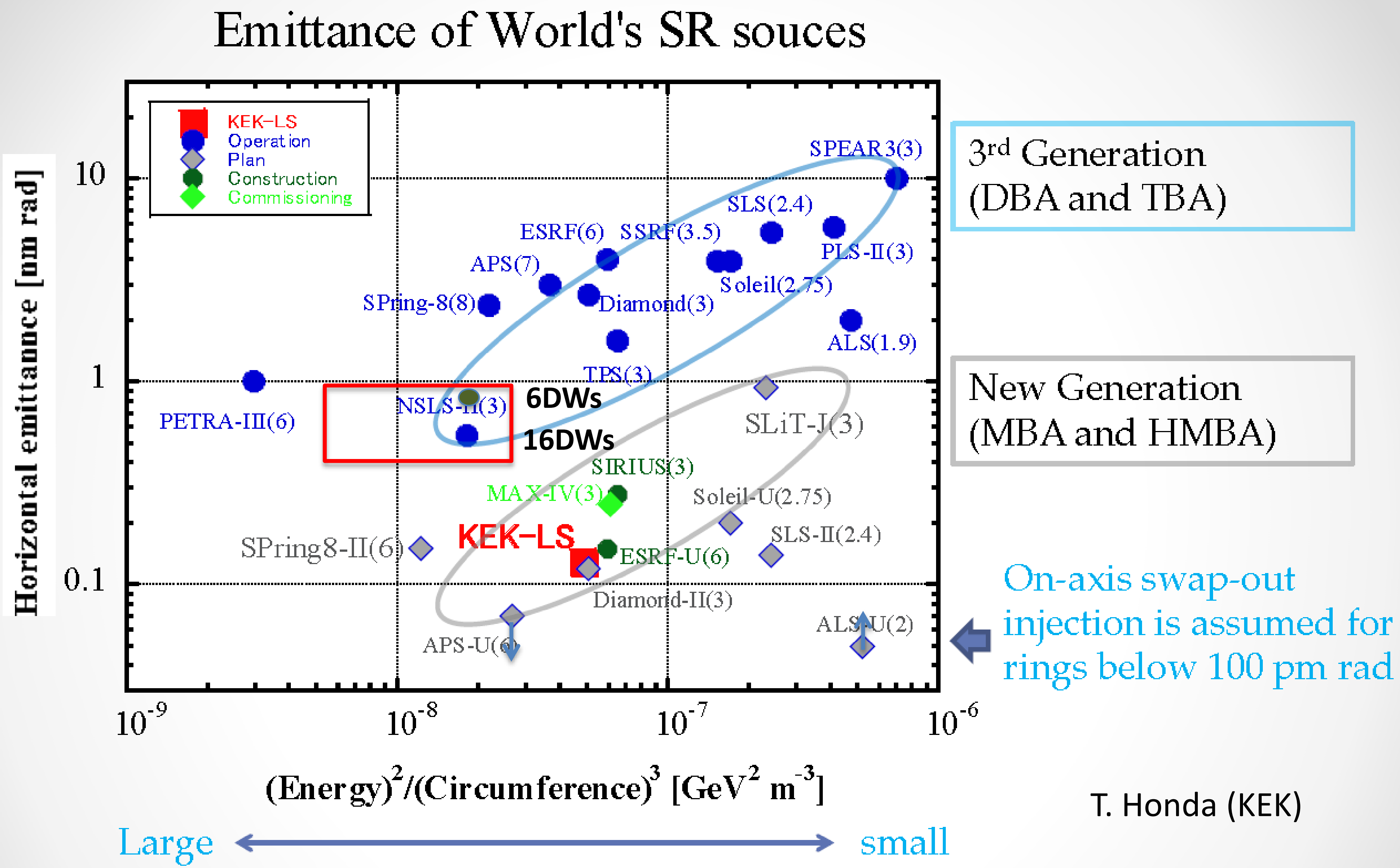
Part-time members: Y. Hidaka, O. Chubar and C. Spataro

Accelerator Physics: A. Blednykh and Y. Li

Vacuum Group: Charles Hetzel and Charles De La Parra

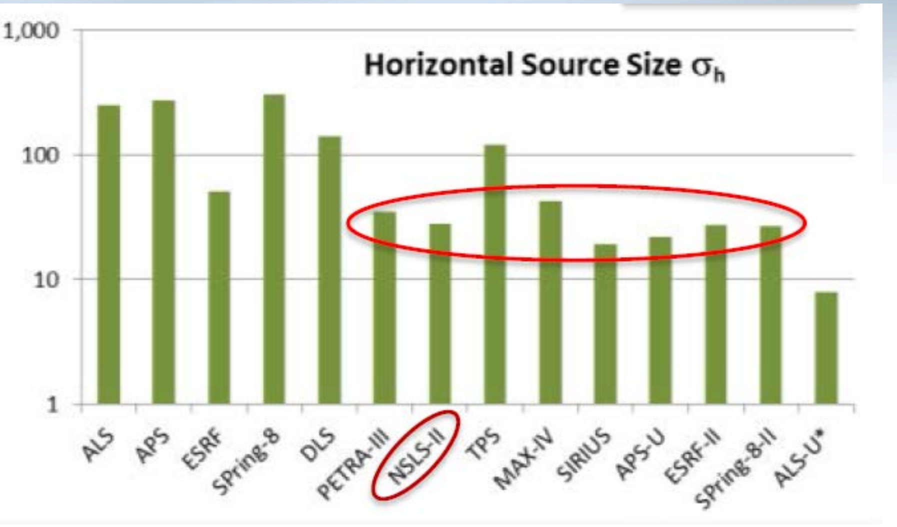
Various Beamline Group Members

Evolution of LS



T. Honda (KEK)

NSLS-II



A 3rd Generation Synchrotron Light Source

Min Beam size: $\boldsymbol{\sigma}_X$ = 28 μm; $\boldsymbol{\sigma}_Y$ = 2.6 μm;
bunch length = ~ 4.5 mm

$\boldsymbol{\varepsilon}_X$ = 0.9 nm-rad (w. 6 DWs) $\boldsymbol{\varepsilon}_Y$ = 8 pm-rad

Accelerators:

200-MeV Linac

3-GeV Booster, 1-2 Hz, C = 158.4 m

3-GeV SR: I = 500 mA, C = 792 m, 30 Achromatic DBA cells

Experimental Facilities:

19 ID+BM Beamlines as of March 2017

Capable of hosting 60+ beam lines

Feb 2009 Start of Construction

Mar 2012 Linac Beam Commissioning

Dec 2013 Booster Beam Commissioning

April 2014 SR Beam Commissioning Started

Jan 2015 Stable Beam for Users

July 2015 Designated as DOE's User Facility

Oct 2015 Top-up operation started

NSLS-II Storage Ring Current Status

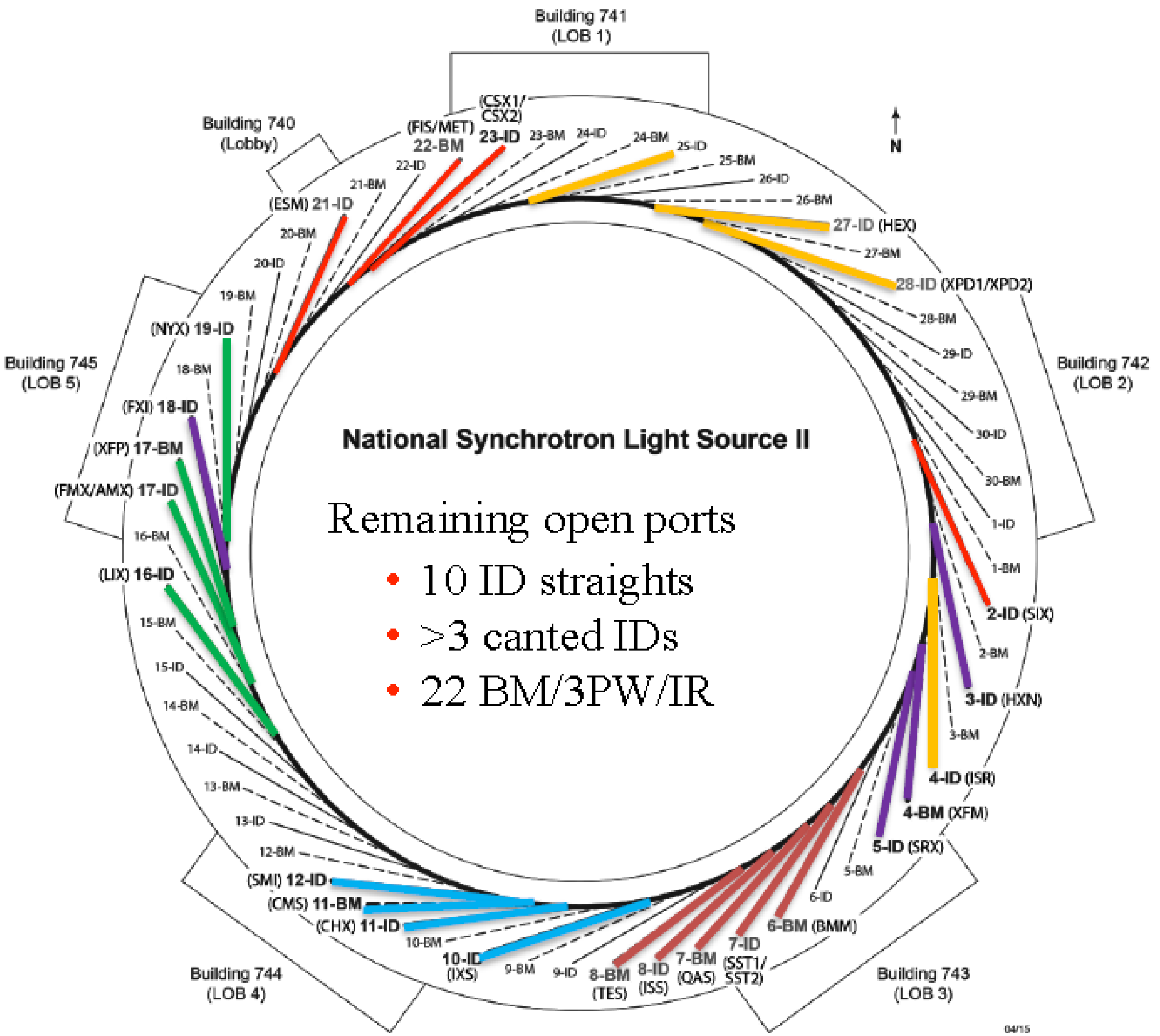
- Max current of 400mA with two SRFs w/o IDs closed. Normal operation at 300mA with top-off.
- The third cavity is planned to be installed to start 500mA operation in 2019.
- ε_y**<8pm** with all IDs closed has been achieved. (only two out of 19 beam lines prefer low emittance mode)
- Beam stability of ~1% in horizontal and <10% in vertical beam size with FOFB on.
- Eight IVUs, Five EPUs, Six DWs, Five 3PWs One In-Air Device (refurbished ESRF) are in place.
- Refurbished EPU60 from SRC is to be installed in August17 shutdown

Tandem EPUs: 1.4m-EPU57 & 2.7m-QEPU105

Canted 2.8m In-Vacuum Undulator (IVU23)

Superconducting RF

NSLS-II Beamline Portfolio



Remaining open ports

- 10 ID straights
- >3 canted IDs
- 22 BM/3PW/IR

Soft X-Ray Scattering & Spectroscopy

23-ID-1: Coherent Soft X-ray Scat (2015)
23-ID-2: Coherent Soft X-ray Spectr & Pol (2015/2016)
21-ID: Photoemission-Microscopy Facility (2017)
2-ID: Soft Inelastic X-ray Scattering (2017)
22-BM: Magneto, Ellipso, High Pressure IR (2018)

Complex Scattering

10-ID: Inelastic X-ray Scattering (2015)
11-ID: Coherent Hard X-ray Scattering (2015)
11-BM: Complex Materials Scattering (2016)
12-ID: Soft Matter Interfaces (2017)

Diffraction & In Situ Scattering

28-ID-1: X-ray Powder Diffraction (2015)
28-ID-2: X-ray Powder Diffraction (2017)
4-ID: In-Situ & Resonant X-Ray Studies (2017)
27-ID: High Energy X-ray Diffraction (2020)
25-ID: Materials in Radiation Environments (2020?)

Hard X-Ray Spectroscopy

8-ID: Inner Shell Spectroscopy (2017)
7-BM: Quick X-ray Absorption and Scattering (2016)
8-BM: Tender X-ray Absorption Spectroscopy (2017)
7-ID-1: Spectroscopy Soft and Tender (2017)
7-ID-2: Spectroscopy Soft and Tender (2017)
6-BM: Beamline for Mater. Measurements (2017)

Imaging & Microscopy

3-ID: Hard X-ray Nanoprobe (2015)
5-ID: Sub-micron Res X-ray Spec (2015)
4-BM: X-ray Fluorescence Microscopy (2017)
18-ID: Full-field X-ray Imaging (2018)

Structural Biology

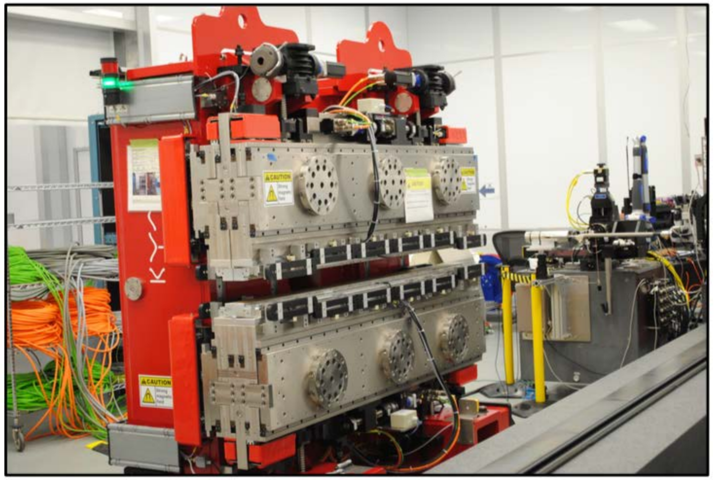
17-ID-1: Frontier Macromolecular Cryst (2016)
17-ID-2: Flexible Access Macromolecular Cryst (2016)
16-ID: X-ray Scattering for Biology (2016)
17-BM: X-ray Footprinting (2016)
19-ID: Microdiffraction Beamline (2017)

• NSLS-II Insertion Devices

- Damping Wiggler (DW)
- APPLE-II Type Elliptically Polarizing Undulator (EPU)
- In-Vacuum Undulator (IVU)
- Three Pole Wiggler (3PW) –Sometimes called Wavelength Shifter

NSLS-II Insertion Devices

Five Apple-II EPUs (Four different types)



by Kyma SRL

Nine In-Vacuum Undulators (IVUs)

by Hitachi Metal America (Neomax)

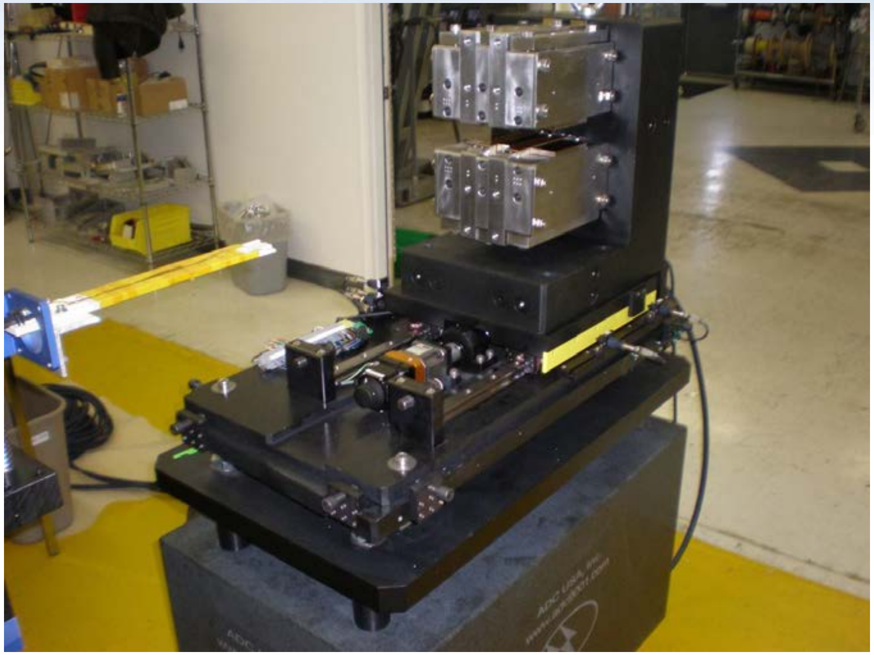
Six 3.4-m hybrid 1.8T PM damping wigglers

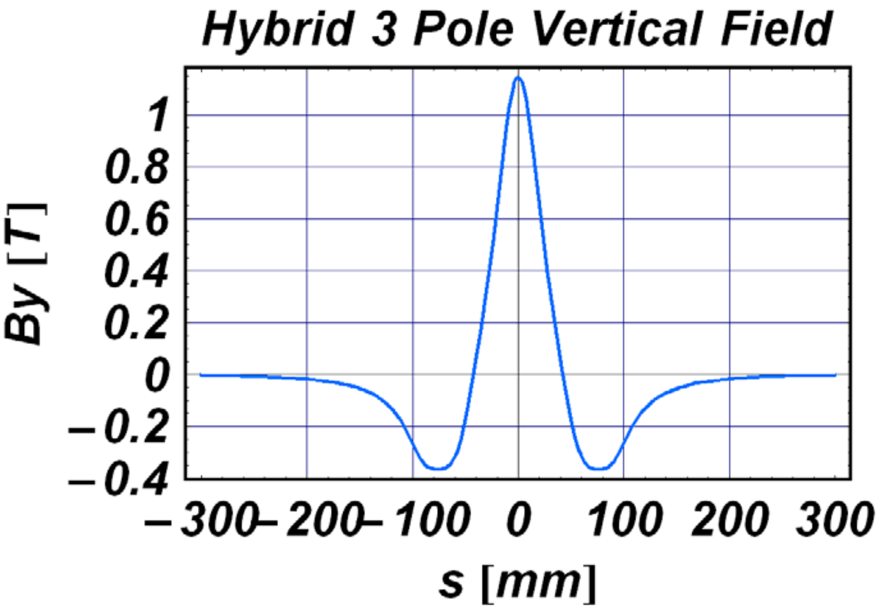
by Danfysik

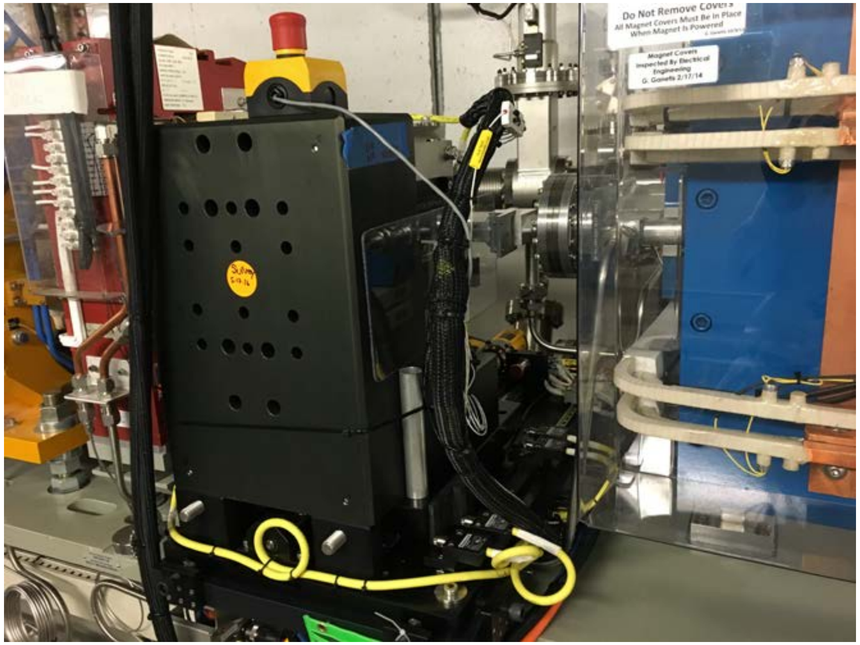
Refurbished in-house design IVU18

8

Three Pole Wiggler (3PW)





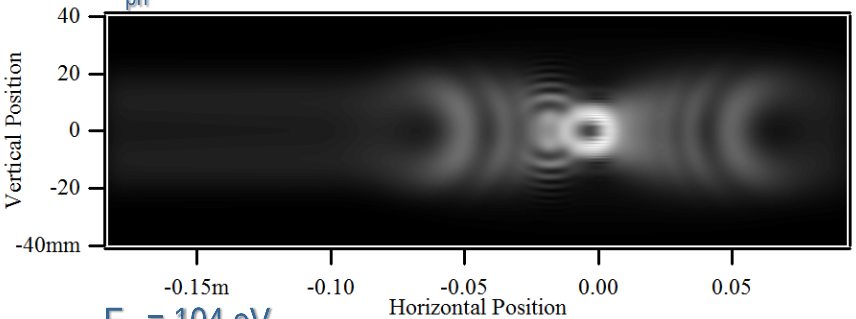


3PW+BM Radiation Intensity Distributions

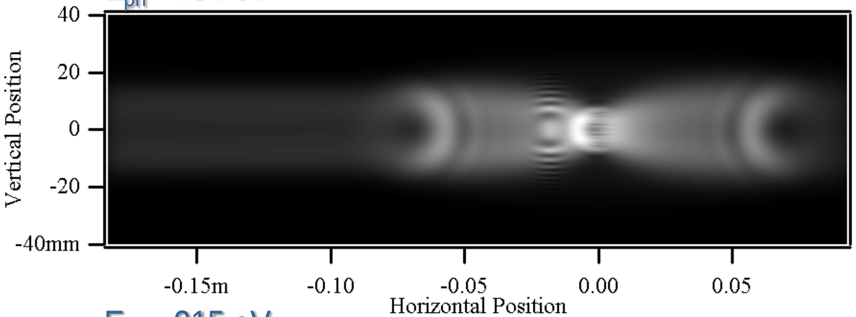
Observation Distance: 30 m (from 3PW Central Pole)

O. Chubar

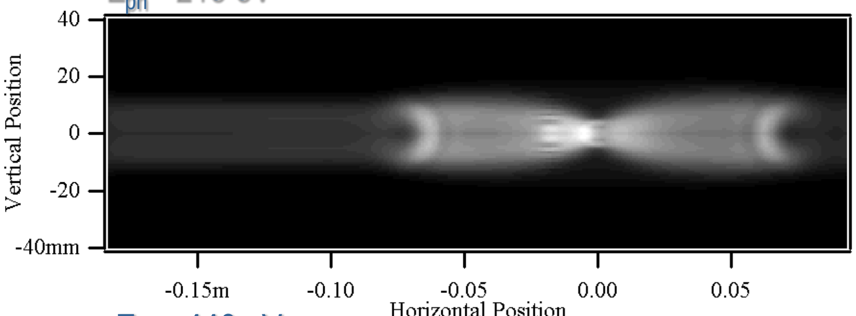
E_{ph}= 50 eV



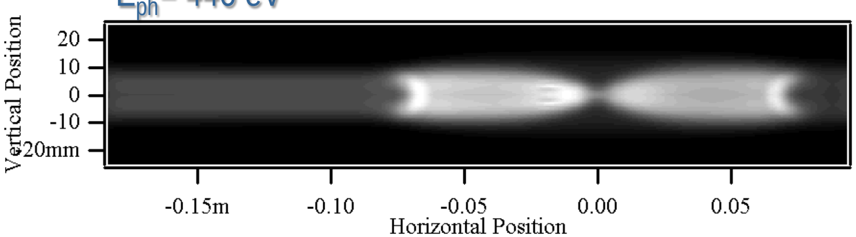
E_{ph}= 104 eV



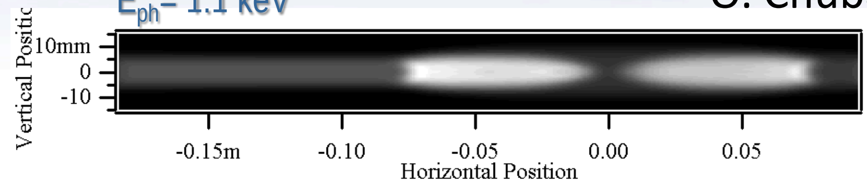
E_{ph}= 215 eV



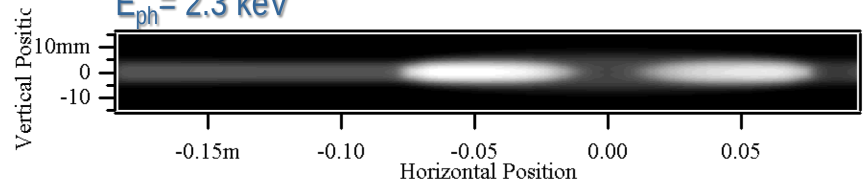
E_{ph}= 446 eV



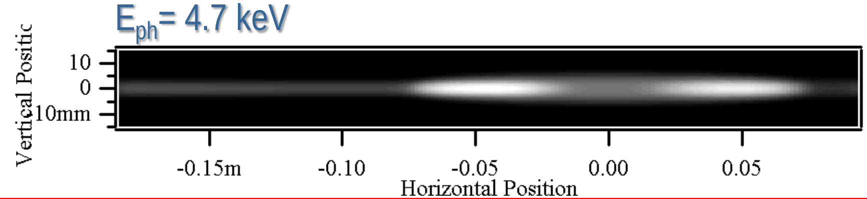
E_{ph}= 1.1 keV



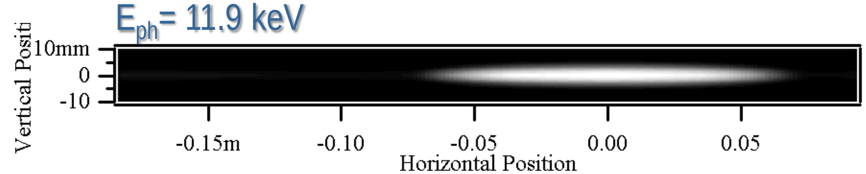
E_{ph}= 2.3 keV



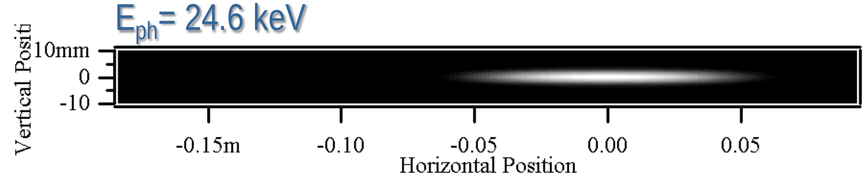
E_{ph}= 4.7 keV



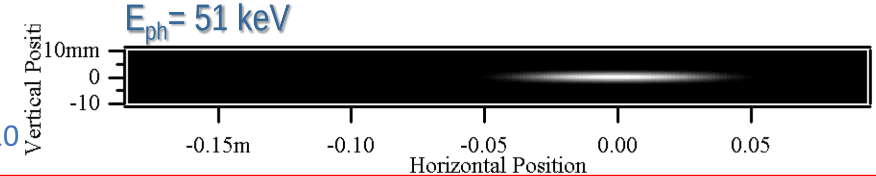
E_{ph}= 11.9 keV



E_{ph}= 24.6 keV



E_{ph}= 51 keV



NSLS-II Insertion Device List (Project IDs)

Beam Line	Type	Design	Beam port	Location	Length [m]	Period [mm]	Peak Field [T]	K_{max}	Canting Angle [mrad]	Vac Aper [mm]	Fund. [eV]	Total Power [kW]
CSX1 /CSX2	EPU49	PPM	Low-β_x	23-ID	4 (2×2)	49	0.57 (heli) 0.94 (Lin) 0.72 (vlin) 0.41 (45d)	2.6 (heli) 4.3 (Lin) 3.2 (vlin) 1.8 (45d)	0.16	8.0	230 (heli) 180 (Lin) 285 (vlin) 400 (45d)	7.3 (heli) 9.9 (Lin) 5.5 (vlin) 1.7 (45d)
IXS	IVU22	Hybrid	High-β_x	10-ID	6 (1×3) center	22	1.52	1.52	0	7.2	1802	4.7x2
HXN	IVU20	Hybrid	Low-β_x	3-ID	3	20	1.03	1.83	0	5.0	1620	8.0
CHX	IVU20	Hybrid	Low-β_x	11-ID	3	20	1.03	1.83	0	5.0	1620	8.0
SRX /(XFN)	IVU21	Hybrid	Low-β_x	5-ID	1.5 downstream	21	0.90	1.79	2.0	6.2	1570	3.6
XPD /PDF	DW100	Hybrid	High-β_x	28-ID	6.8 (2×3.4)	100	1.8	~16.5		11.5		64.5

- Total 7 Insertion Devices (IDs) installed and commissioned as part of NSLS-II Project

NSLS-II Insertion Device List (NEXT, ABBIX, Partner)

Beam Line	Project	Type	Design	Beamport	Location	Length [m]	Period [mm]	Peak Field [T]	K_{max}	Canting Angle [mrad]	Vac Aper [mm]	Total Power [kW]
ESM	NEXT	EPU105/ EPU57	PPM	Low-β_x	21-ID	2.7/1.4	105/49	0.74/0.57 (heli) 0.90 (vlin) 1.14/0.83 (Lin)	7.23/3.55 (heli) 7.23/3.06(vlin) 11.2/4.4 (Lin)	2.0		4.22/1.2 (heli) 4.22/0.86 (vlin) 10.1/2.0 (Lin)
SIX	NEXT	EPU57	PPM	High-β_x	2-ID	7.0 (2×3.5)	57	0.57 (heli) 0.83 (Lin)	3.55 (heli) 4.41 (Lin)	0		4.4 (heli) x2 6.8 (Lin) x2
ISR	NEXT	IVU23	Hybrid	High-β_x	4-ID	2.8	23	0.95	2.05	2.0	6.0	
SMI	NEXT	IVU23	Hybrid	High-βx	12-ID	2.8	23	0.95	2.05	2.0	6.0	
ISS+XFP	NEXT	DW100	Hybrid	High-β_x	18-ID	6.8 (2×3.4)	100		~16.5		11.5	64.5
FXI	NEXT	DW100	Hybrid	High-β_x	8-ID	6.8 (2×3.4)	100		~16.5		11.5	64.5
LIX	ABBIX	IVU23	Hybrid	High-β_x	16-ID	2.8	23	1.02	2.2	0	5.5	
FMX/AMX	ABBIX	IVU21	Hybrid	Low-β_x	17-ID	1.5 x 2	21	0.90	1.79	2.0	6.2	3.6
SST	Partner	U42	Hybrid	Low-β_x	7-ID	1.6	42	0.82	3.27	2.0	8.0	3.2
	Partner	EPU60	PPM	Low-β_x	7-ID	0.89	60	0.73 (heli) 1.02 (Lin)	4.1 (heli) 5.7 (Lin)		8.0	1.8 (heli) 2.7 (Lin)
NYX	Partner	IVU18	Hybrid	Low-β_x	19-ID	1.0	18	0.95	1.55	0	5.4	2.5
HEX	Partner	SCW80	EM	Low-β_x	27-ID?	1.0	55	4.2	21.6	0	10	49.7

- 11 additional IDs installed so far (9 commissioned) as part of 3 different projects
- 1 more ID (SST) soon to be installed
- 2 SCWs (1.2m, 80mm period, 4.5T) planned in coming years

- NSLS-II ID-Mag. Meas. Facility
  - Coil Measurement System
  - Hall probe bench
  - In Vacuum Magnetic Measurement System
  - Our Cross Calibration Results
  - Multipole Measurement for Small Gap ID

ID-MMF (Coil Measurement System, Hall probe bench)

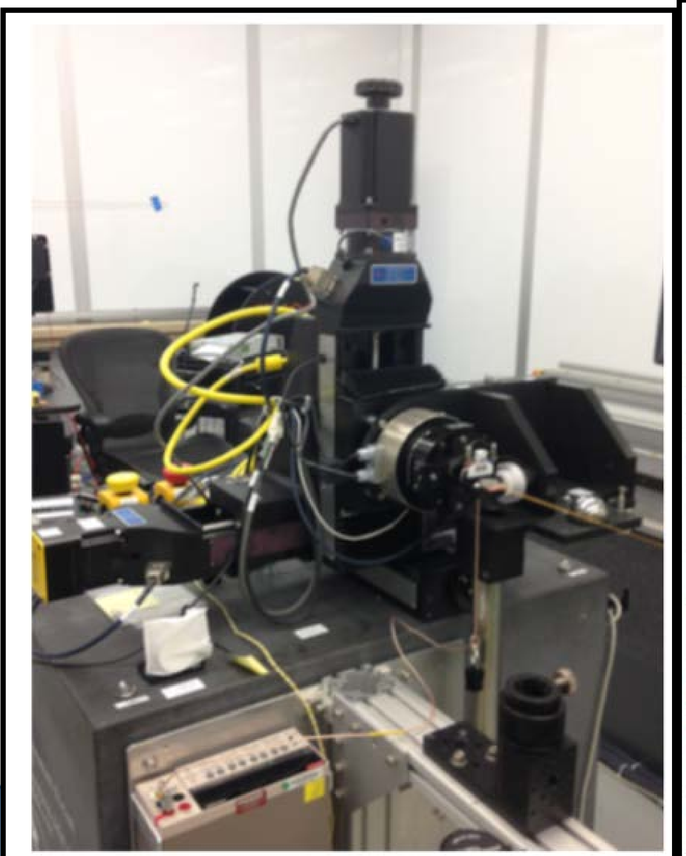
Integrated Field Measurement System by ADC USA Inc

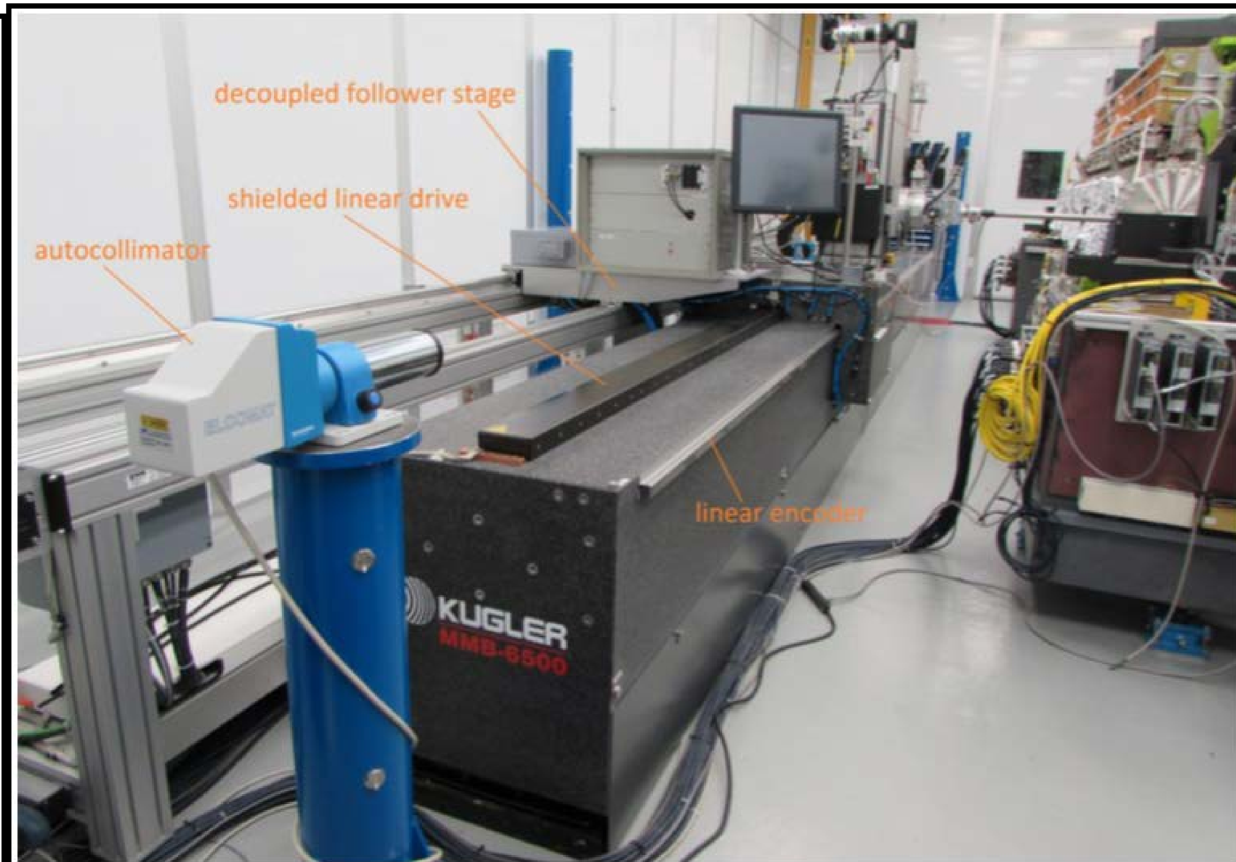
- Reference surface flatness ±5 **μm**.
- Weight of each granite support: 1580 kg

3D Hall probe bench MMB-6500 by Kugler, GmbH

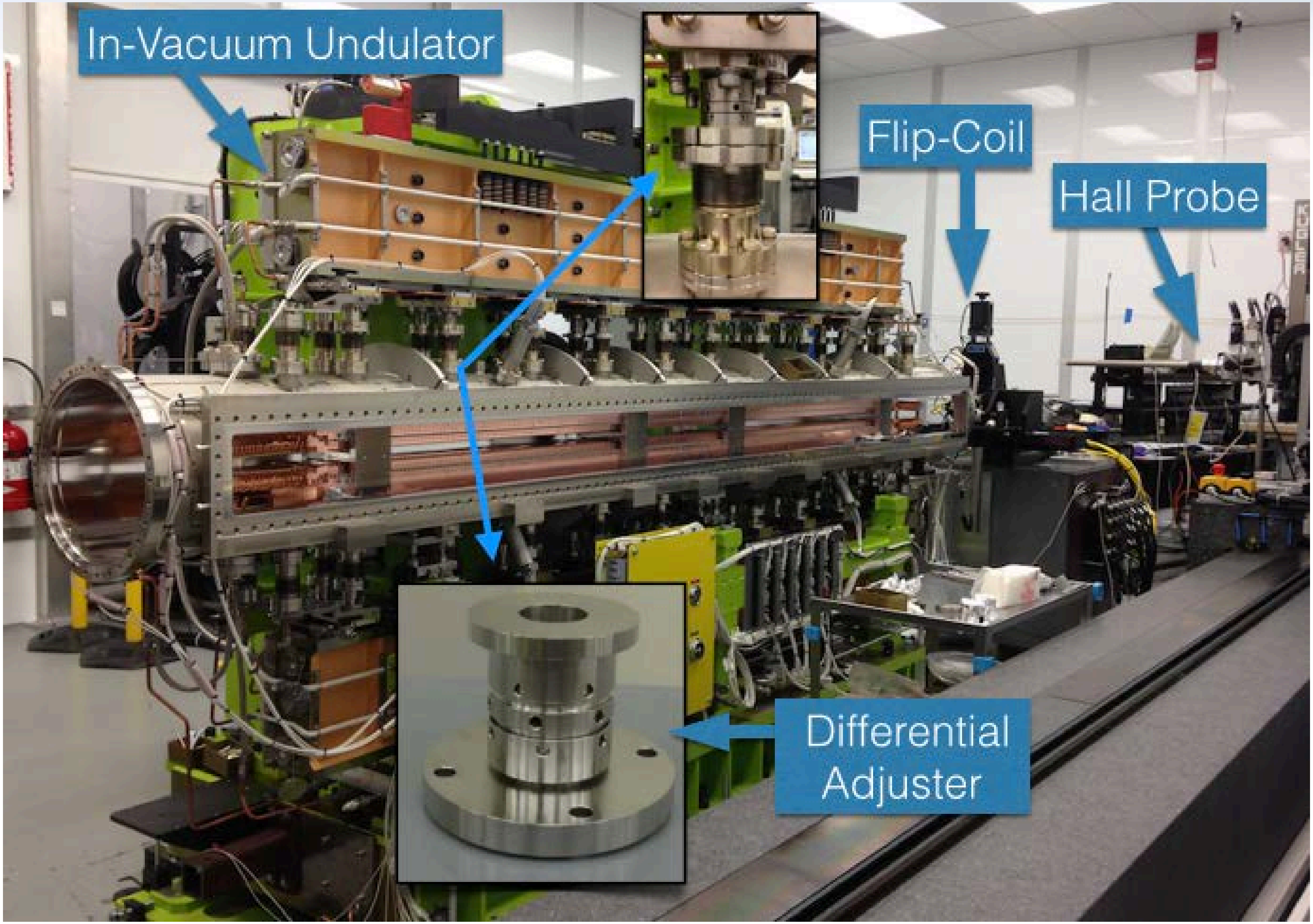
- SENIS 3D Hall Probe (Type P for H3A)
- Flatness deviation < ± 3 μm
- Longitudinal Positioning accuracy < ± 1 **μm**.
- 9 Motion Controlled Axes.

Details: M. Musardo (IMMW19)



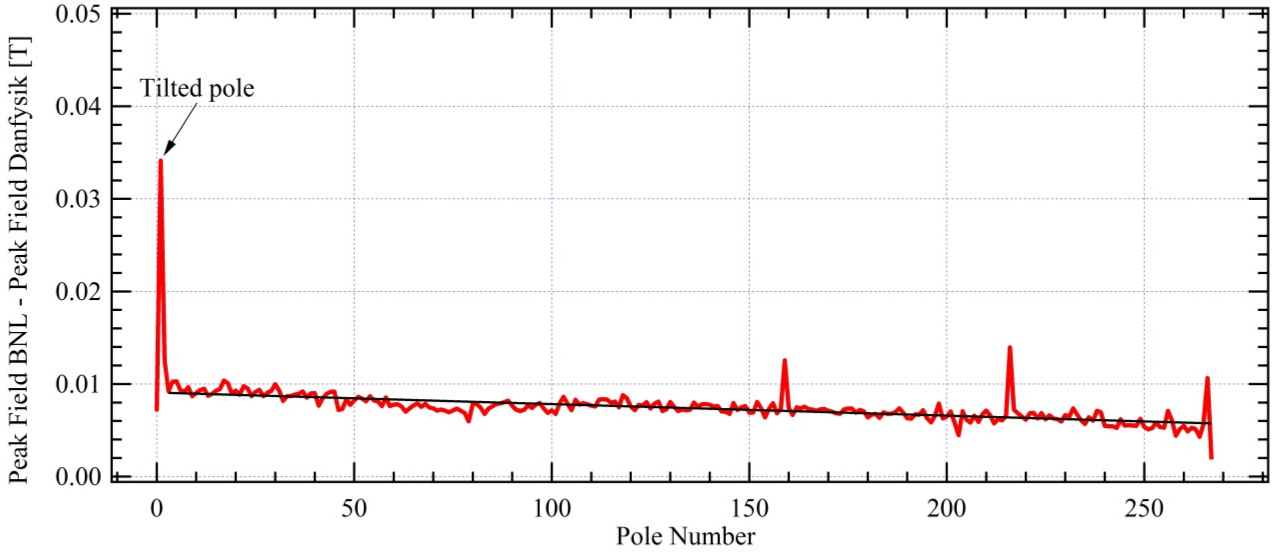


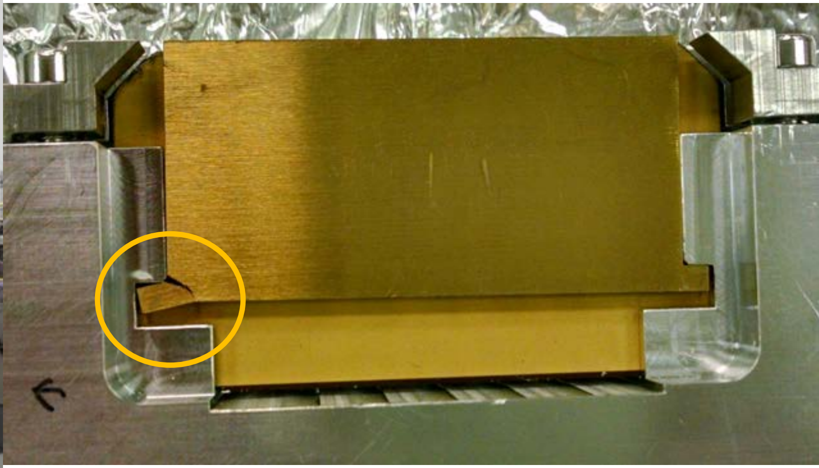
In-Vacuum Undualtor with a "Side Window"at ID-MMF



Magnetic Measurement Revealed Pole Damage in an IVU

BNL's mag measurement revealed that there was a big error in the first peak field value

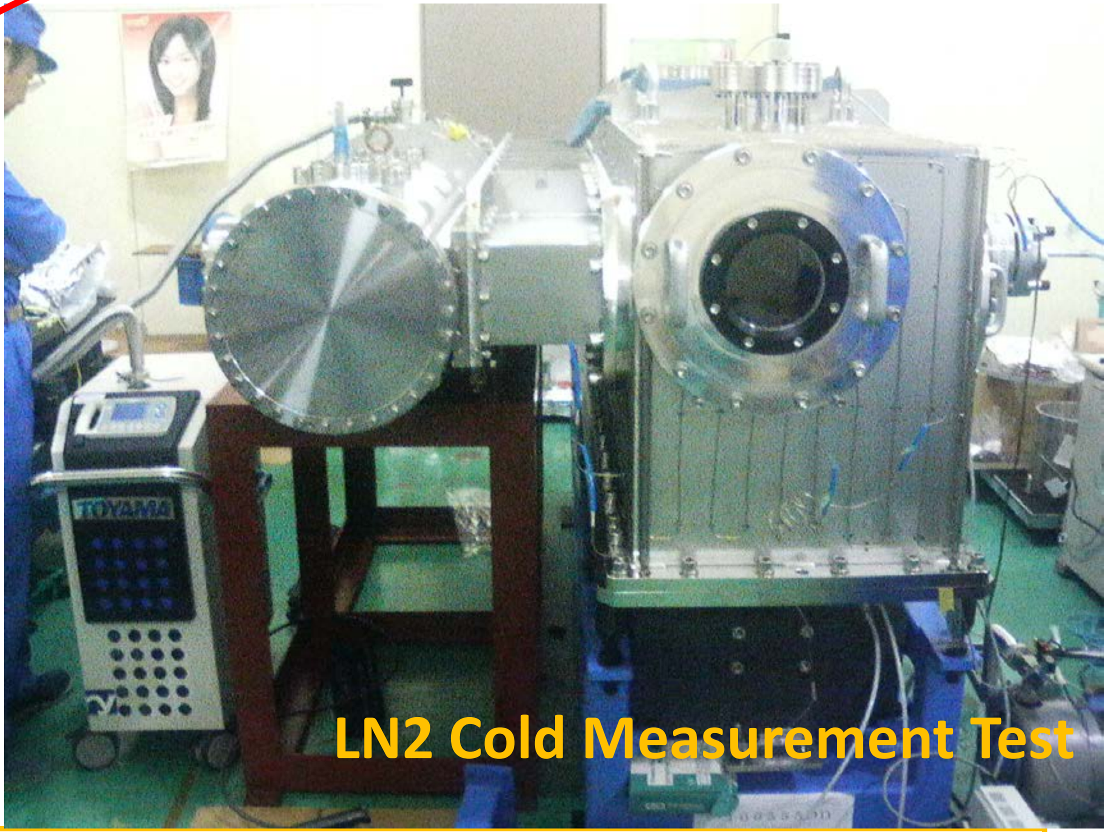




Later Fixed in the tunnel !!

In-Vacuum Magnetic Measurement System (IVMMS) Dec 2012

PrFeB Undulator:λu=17mm, 47CR



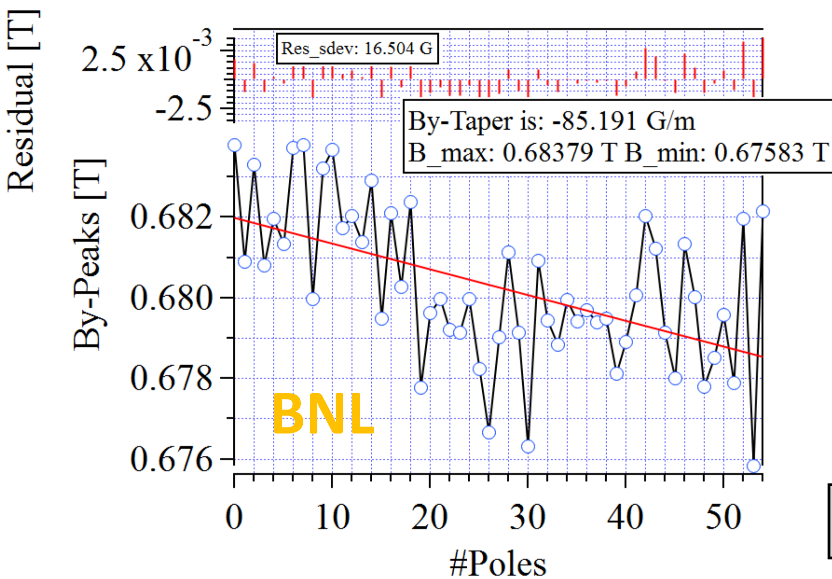
Issues:Thermal load for cryogenic meas.
Vacuum compatible lubricant

Fixed Gap Calibration-Array for Cross-calibration

(1) BNL vs Danfysik

Hall Probe Scan @ X=0 mm

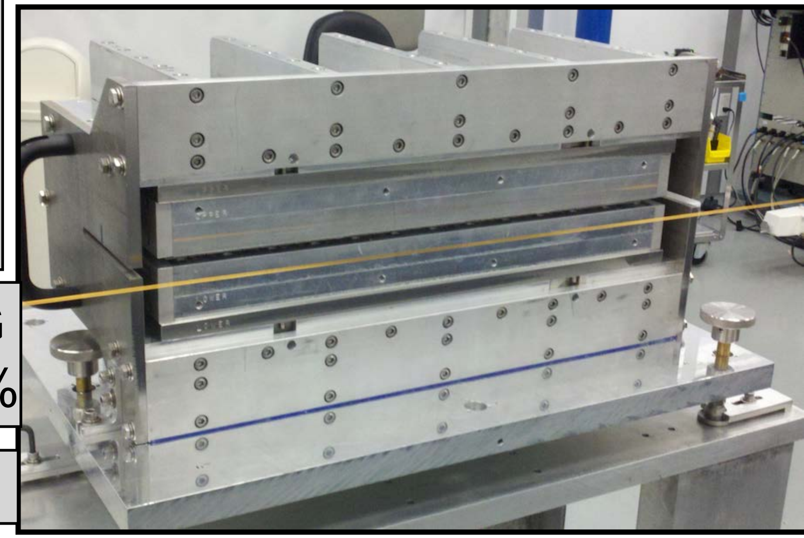
NdFeB - Fixed gap = 5.7 mm, L = 50 cm, λ = 15 mm

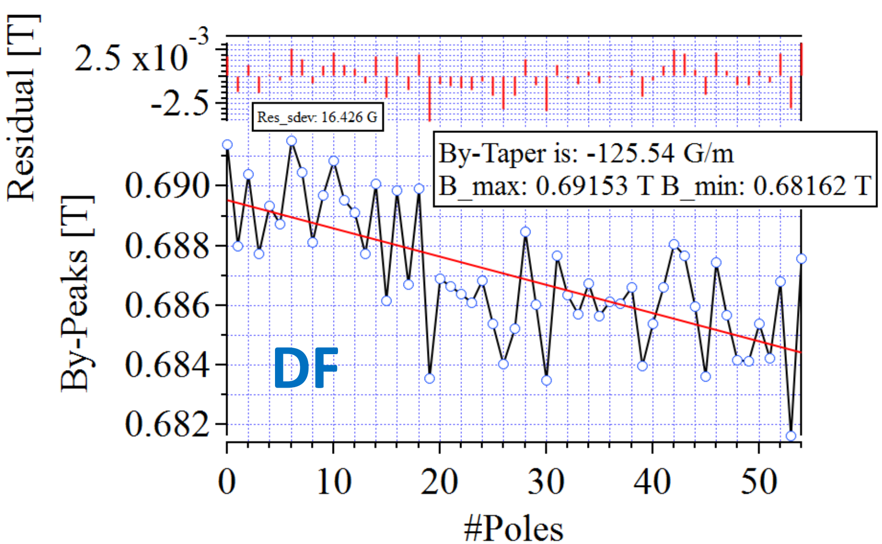


ΔB_{max}= 77 G
∂B_{max} =1.1 %
ΔB_{min}= 58 G
∂B_{min} =0.8 %
ΔTaper = 40 G/m

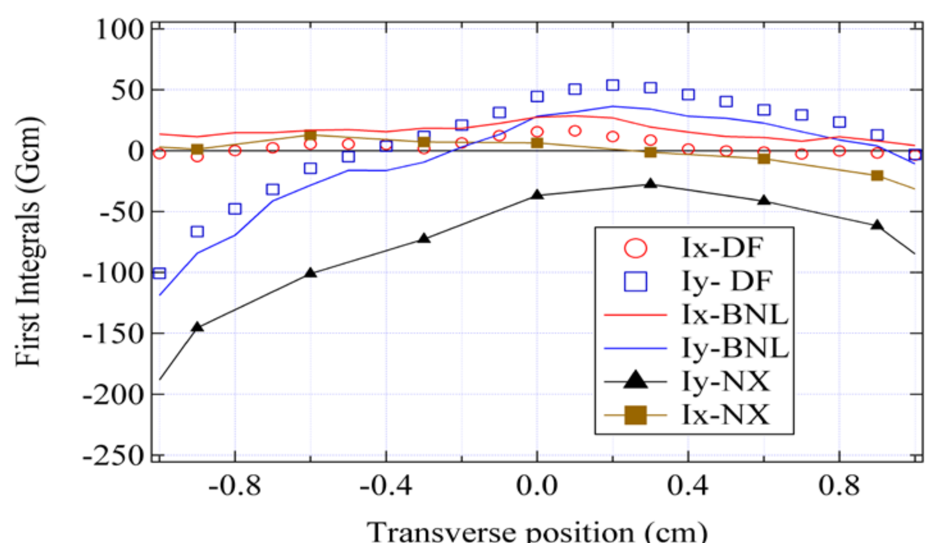
ΔB=67.2 G
∂B= 0.98 %

Δ σ = 0.2 °





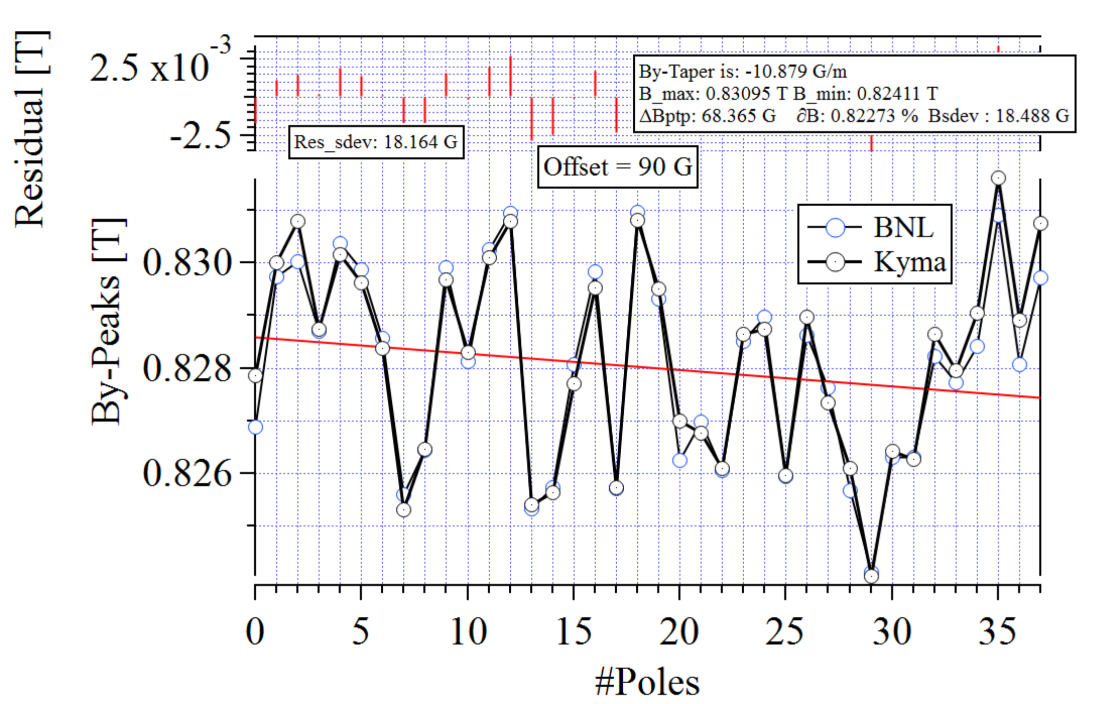
Field Integrals Measurement by 3 Labs

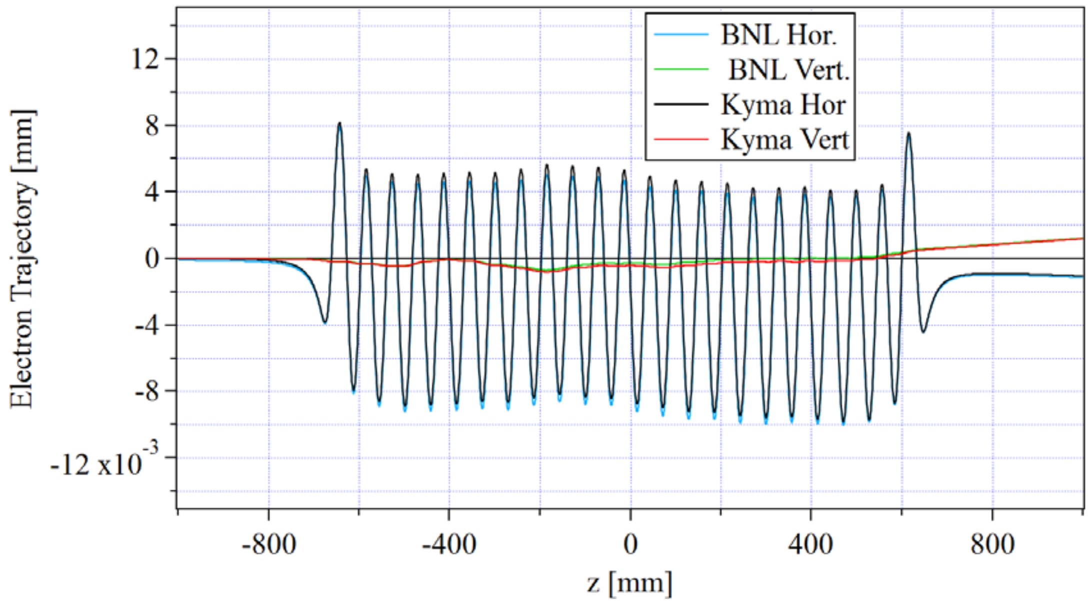


Hall Probe Measurement Comparison for SIX-EPU57

(2) BNL vs Kyma

Peak Field Variation

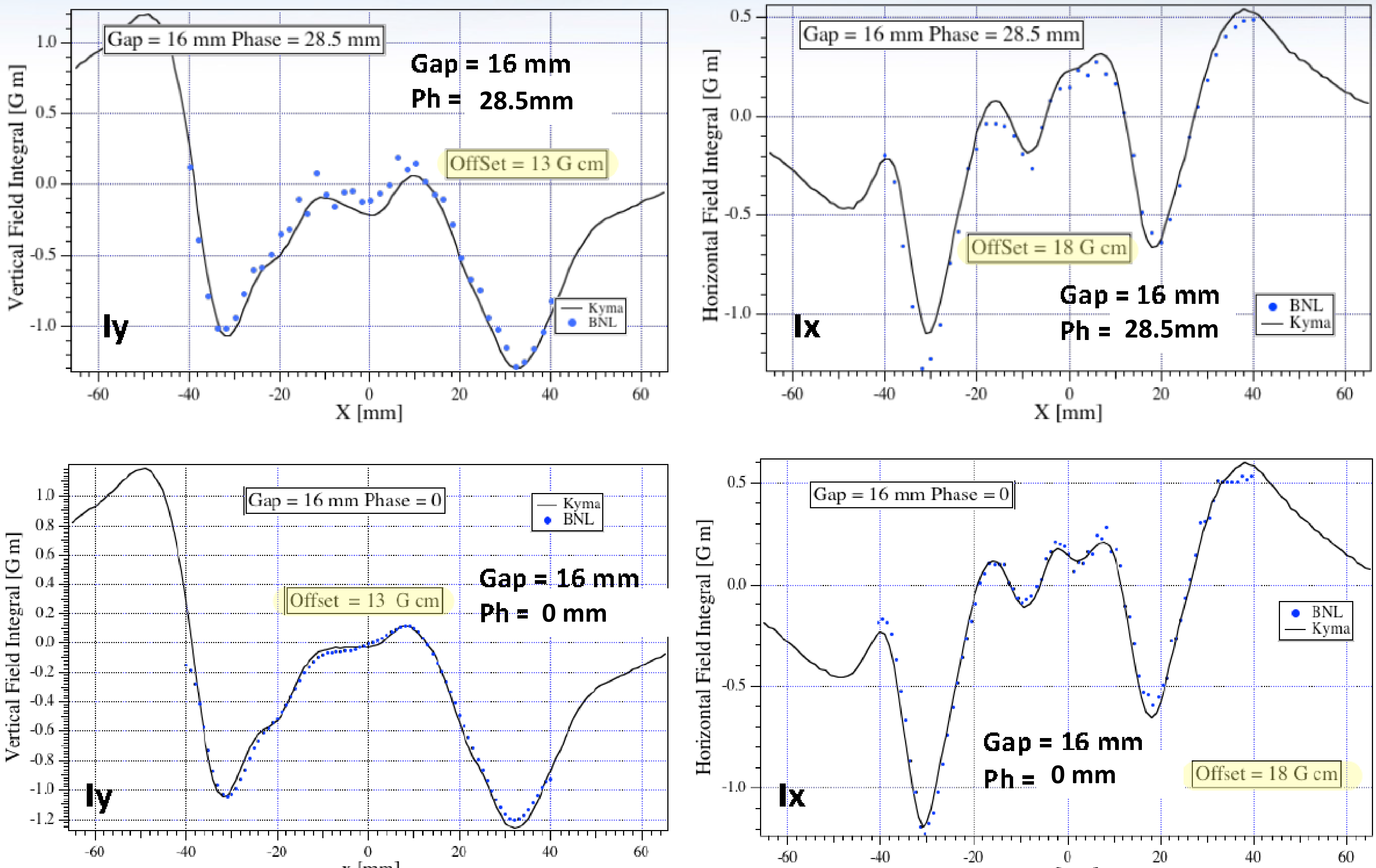




Electron Trajectory @3GeV

Field Integral Comparison for SIX-EPU57

(2) BNL vs Kyma



A Caveat for RMS Phase Error

- Radiation Phase $\phi = k_s z - \omega_s t$ then $\frac{d\phi}{dz} = k_s - \omega_s \frac{1}{\frac{dz}{dt}} = k_s - \frac{\omega_s}{c}\frac{1}{\frac{v_{//}}{c}} = k_s\left(1 - \frac{1}{\beta_{//}}\right)$ $\beta_{//} = \sqrt{\beta^2 - \beta_\perp^2}$

$$(\beta_{//})^{-1} = \left(\beta^2 - \beta_\perp^2\right)^{-\frac{1}{2}} = \left(1 - \frac{1}{\gamma^2} - \beta_\perp^2\right)^{-\frac{1}{2}} \approx 1 + \frac{1}{2\gamma^2} + \frac{\beta_\perp^2}{2}$$

Therefore, the phase advance over the distance S is

$$\phi(S) = \frac{k_s}{2}\left[\frac{S}{\gamma^2} + \int_0^S \left|\beta_\perp\right|^2 ds\right]$$

RMS Phase Errors with N periods

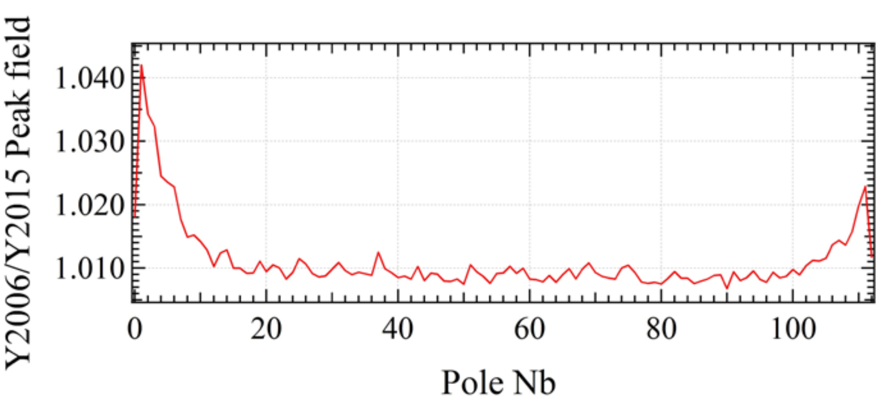
$$\phi_{rms} = \sum_{i=1}^{2N} \sqrt{(\phi_{ideal} - \phi_i)^2}$$

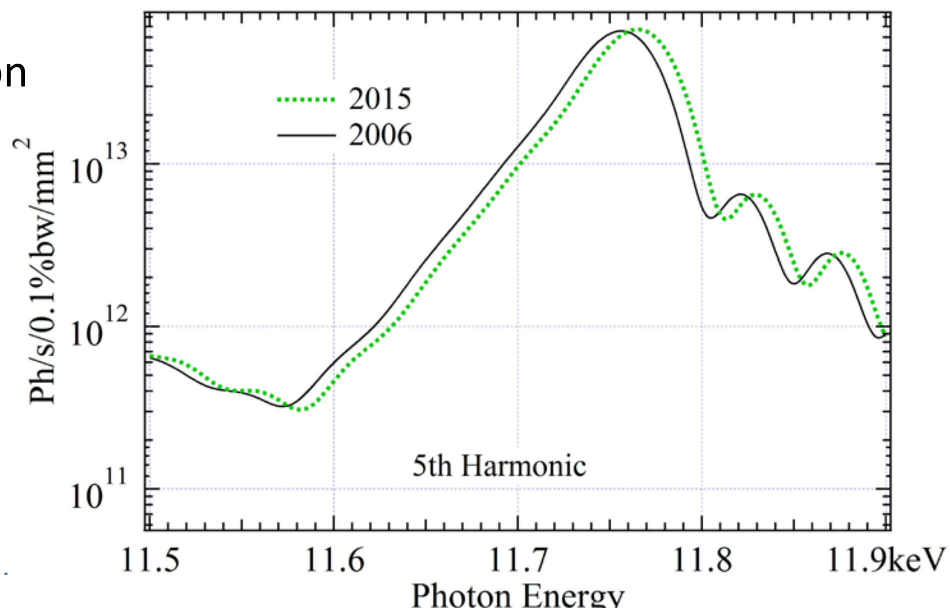
→ However, the below formula is applicable only when the errors are RANDOMLY distributed.

$$Intensity(\deg, n) \approx I_{ideal} e^{-\left(\frac{n\pi \cdot \deg}{180}\right)^2}$$

Calculated spectrum shows very little degradation

Ex: NSLS-IVU18→ Only ends show deterioration after 9 years → PH increased from 1.85° to 2°

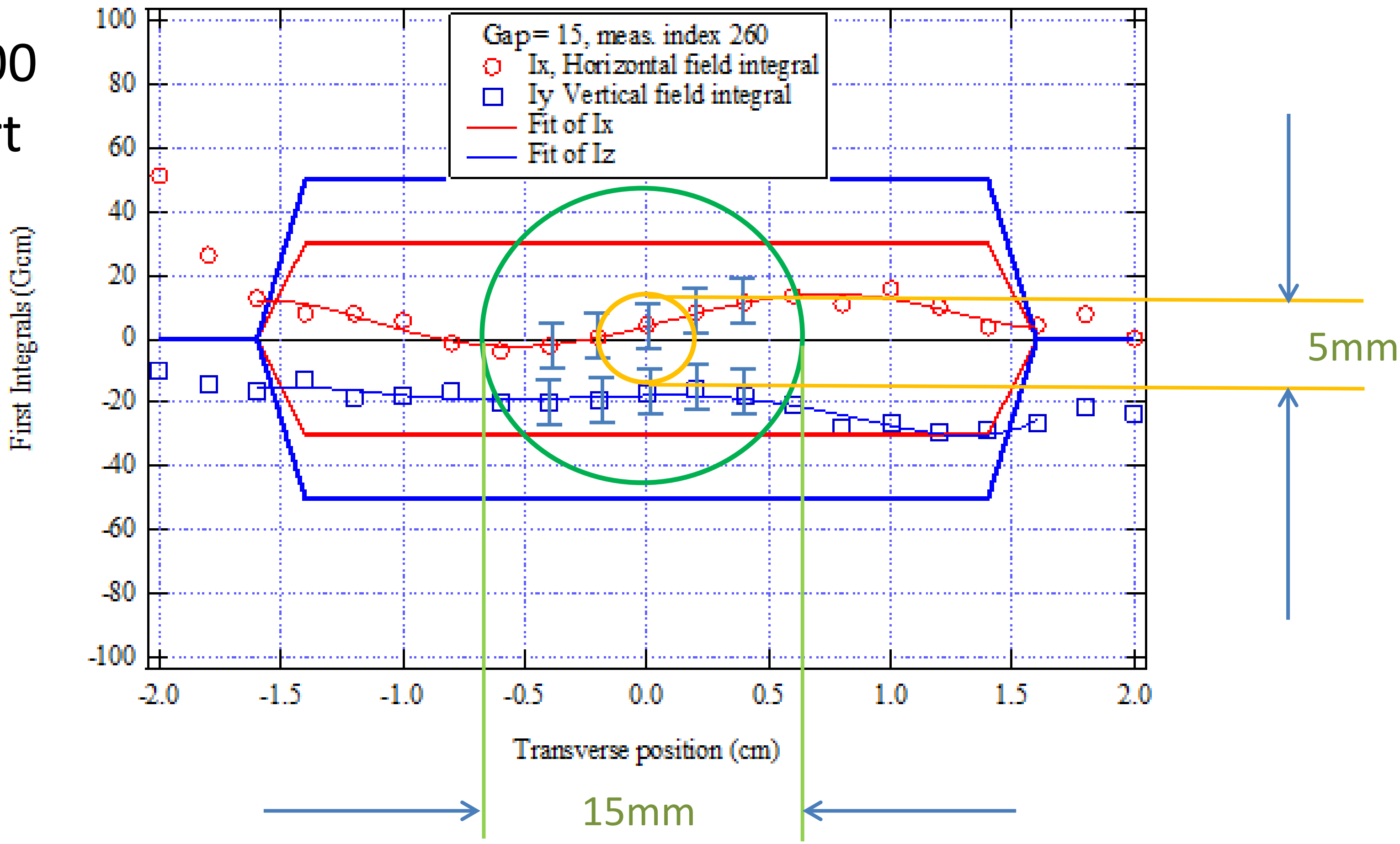




ID Integrated Mutiplole Estimates

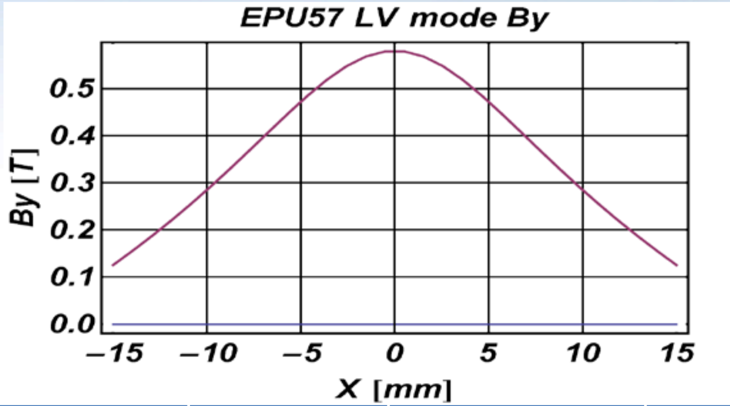
- Note: Multipole expansion is a solution of Laplace equation (i.e. without source). Therefore measurement in horizontal dimension should be equal to the gap value. <u>All the vendors were making this mistake.</u>

DW100 Report



- Beam Based Measurement on 2^{nd} order kicks in APPLE-II EPUs
- Beam Based Field Integral Measurement
- Spectral Based ID Alignment

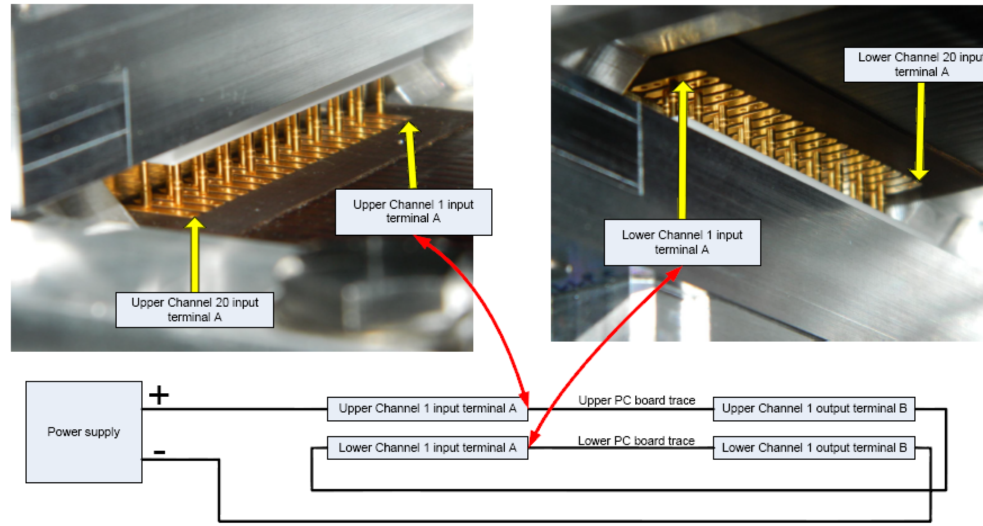
Measurements of 2nd order kick in LV Mode in Apple-II EPU57



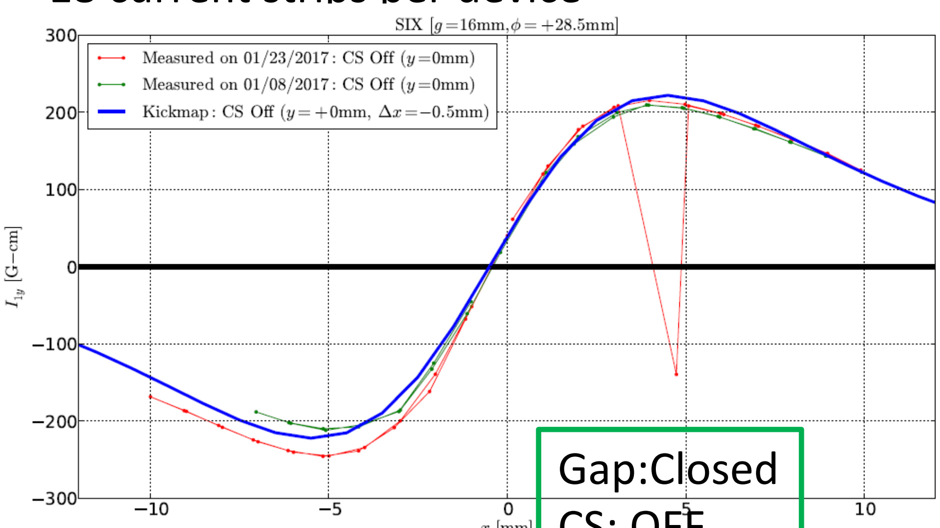
second order kicks (*Elleaume, EPAC 1992*):

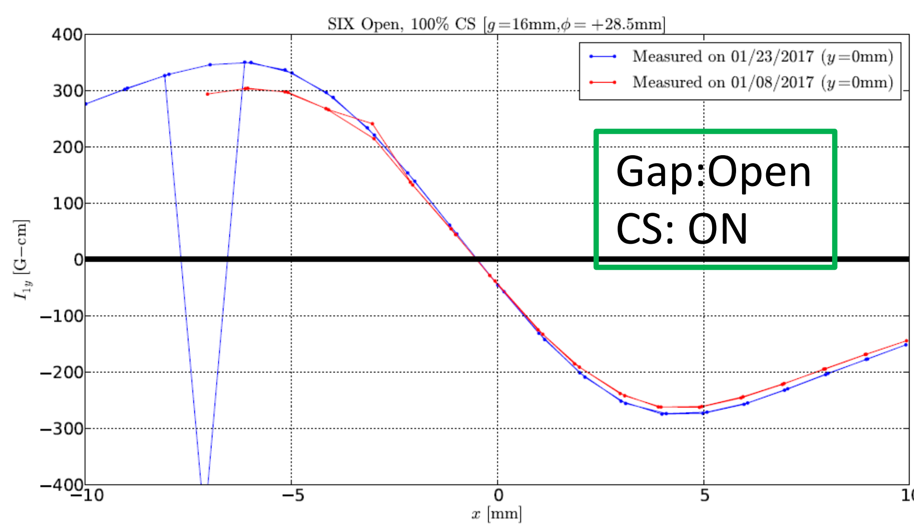
$$\theta_{x/y} = -\frac{1}{(B\rho)^2}\int\left\{\int B_x dz' \cdot \int \frac{\partial B_x}{\partial x/y} dz' + \int B_y dz' \cdot \int \frac{\partial B_y}{\partial x/y} dz'\right\} dz$$

	Open	Closed w/o CS	Closed w/ CS
Measured ν_x	0.20458	0.19216	0.20307
Expected ν_x	N/A	0.19156	0.20422
Measured ν_y	0.25397	0.25804	0.25610
Expected ν_y	N/A	0.25802	0.25567



18 current strips per device



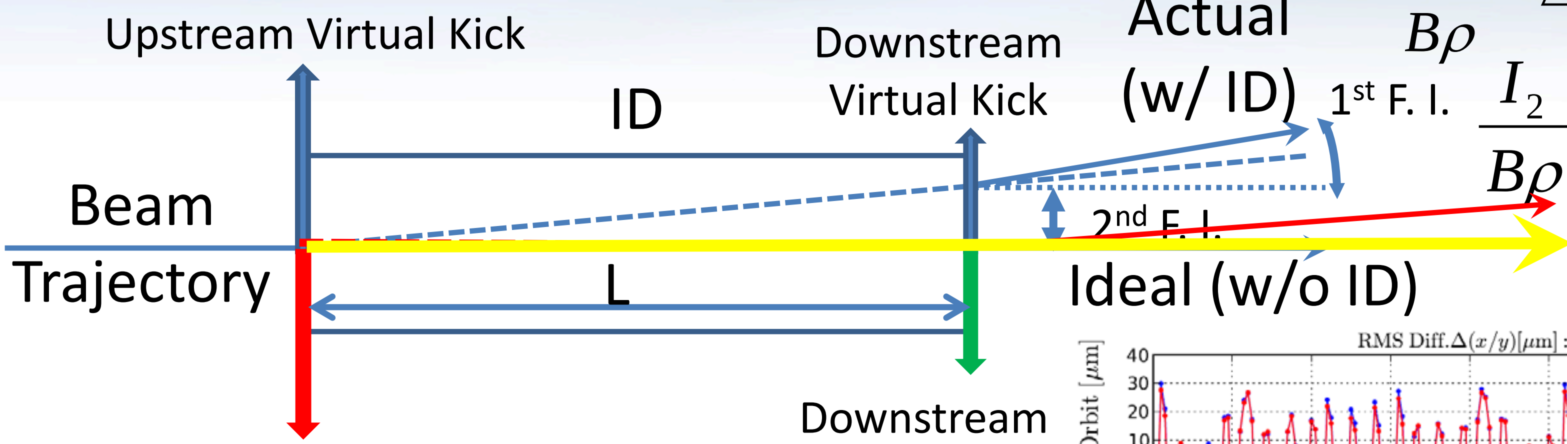


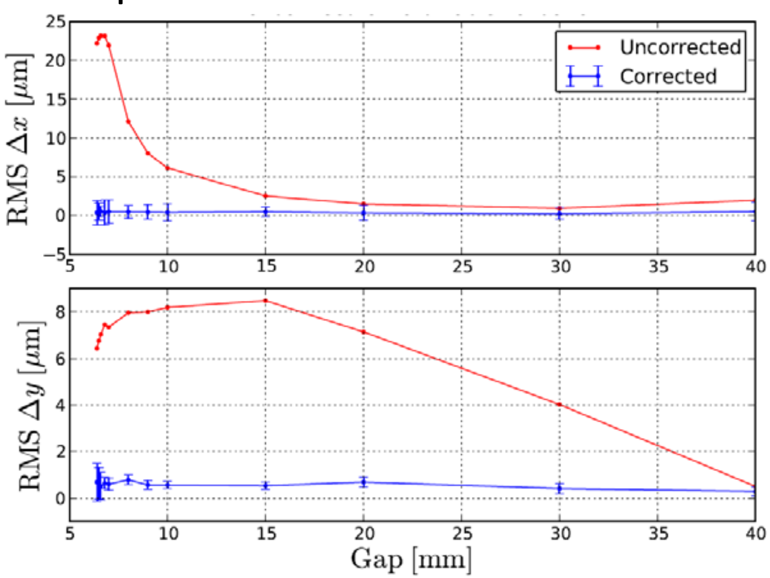
C. Kitegi, Y. Hidaka

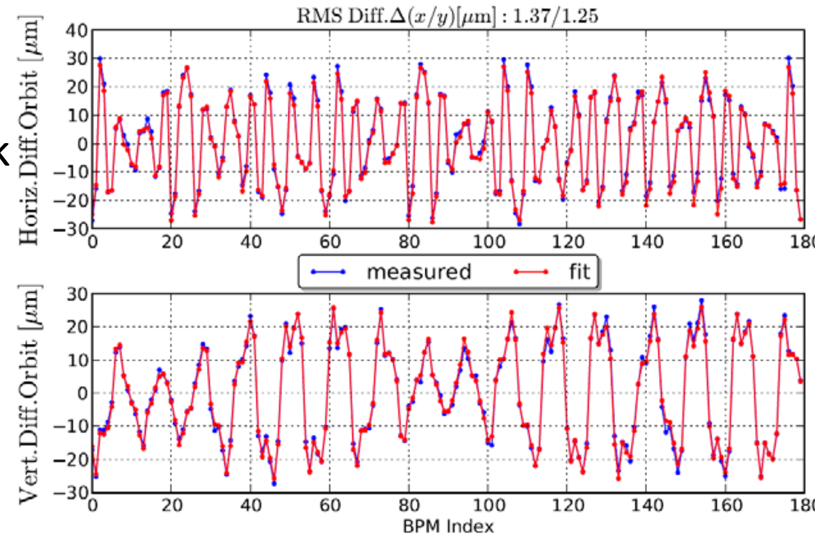
Beam-based Field Integral Measurements

$$\frac{I_1}{B\rho} = \Delta\theta_x = \theta_{US} + \theta_{DS}$$

$$\frac{I_2}{B\rho} = \Delta x = L\theta_{US}$$







- Measure CODs at open & closed gaps
- Treat ID as drift & fit US & DS virtual kick angles that produce measured COD difference
  - Simple formula to estimate I_1 & I_2

$$I_1 = B\rho\left(\theta_{US} + \theta_{DS}\right)$$

$$I_2 = B\rho \cdot L\theta_{US}$$

Not always true!

- Orbit feedforward system applies opposite kicks at both ends to minimize orbit disturbance outside ID.

Field Integrals: Beam-based vs. Flip Coil Meas.

Device	Location	Date	Gap [mm]	Coil ΔI_x [G.cm]	Coil ΔI_y [G.cm]	e-beam ΔI_x [G.cm]	e-beam ΔI_y [G.cm]	RMS Δx [μm]	RMS Δy [μm]
IVU20	C3	2/25/15	6.7	-15.6	3.4	-11.1	-3.4	1.152	0.501
IVU20	C11	2/25/15	6.7	-100.8	11.6	18.0	32.5	1.187	0.593
IVU21	C5	11/15/14	6.2	-71.2	85.8	-104.454	102.777	1.417	1.084
		2/25/15 **	6.5	-90.9*	72.5*	-81.194	88.924	1.199	2.787
IVU22	C10 (LS)	11/21/14	6	214	17.7	-24.237	-15.945	2.419	1.189
		2/25/15	7.2	-109***	41.1***	-63.984	-18.226	2.534	3.014
DW	C8U	12/20/14	15	-21.3	-55.4	-105.159	-99.38	8.818	4.485
		2/25/15	15			-62.961	-79.578	5.546	4.252
	C8D	1/23/15	15	152	159	59.702	215.524	6.066	6.634
		2/25/15	15			42.042	199.967	10.021	5.955
	C18U	12/17/14	15	-22.8	13.7	-144.666	-76.481	5.795	6.456
		2/25/15	15			-96.179	-67.754	4.659	3.454
	C18D	12/20/14	15	3.95	-13.2	-187.691	95.166	5.464	5.249
		2/25/15	15			-213.981	79.656	5.950	9.544
	C28U	12/8/14	15	-95.9	-24.267	141	-57.057	5.106	6.544
		2/25/15**	15			-67.9	-53.881	4.564	3.326
	C28D	12/8/14	15	-30.9	-237	-290	178.495	5.134	17.54
		2/25/15 **	15			-206	160.369	7.758	6.311

***7.5mm gap

**6.8mm gap

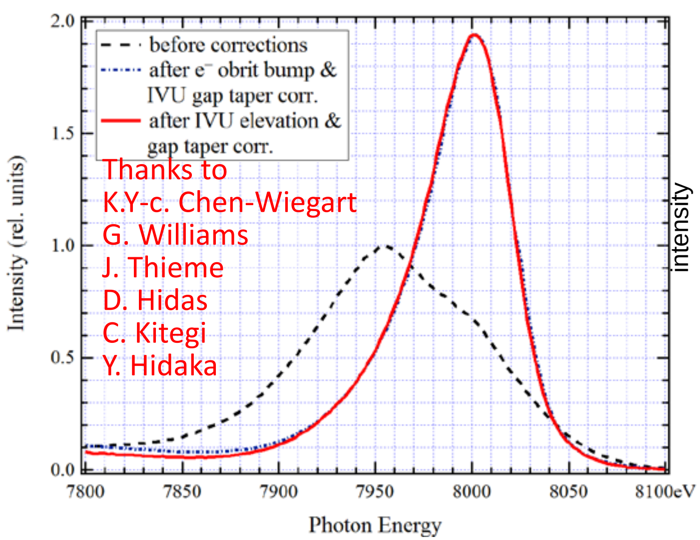
*Realigned after year-end shutdown in 2014

- Beam-based fitting is worse (RMS Δx & Δy) for DWs than for IVUs
  - Stronger focusing effect of wigglers, sensitive to vertical orbit centering
  - Large horizontal wiggling motion => path lengthening
- Many show large discrepancies
  - Potential causes: Earth field variation, nearby ferromagnetic structures, stray B-field, misalignment during installation
  - Found vertical ID corrector strengths for DWs to be insufficient

Examples of Spectrum Based Alignment of IVUs at Hard X-ray Beamlines of NSLS-II

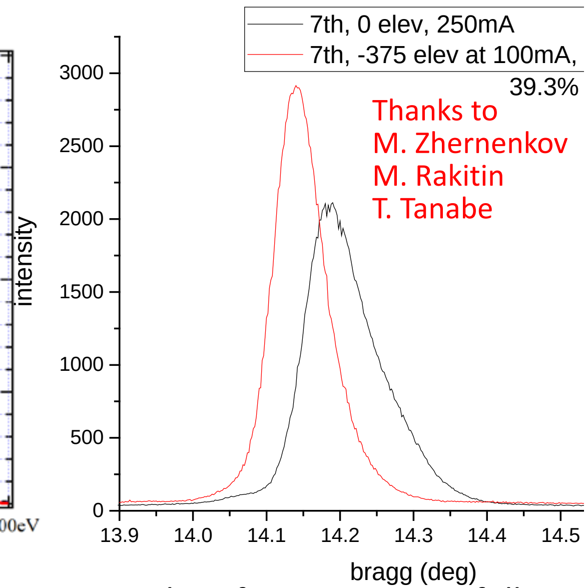
On-Axis UR Spectra Before and After Spectrum Based Alignment

IVU21 - 1.5 m at SRX BL
(harm. #5 at ~6.8 mm gap, ~8.0 keV)



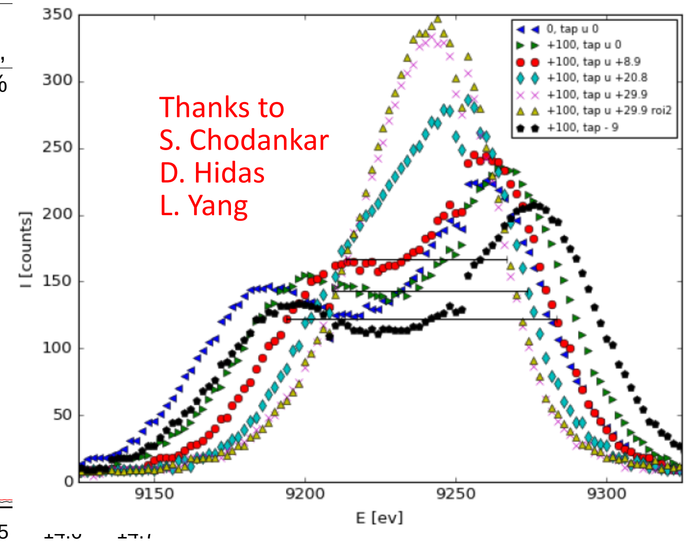
Spectral performance was fully restored by introducing +100 μm change in elevation
and -35 μm change in taper.

IVU23 - 2.8 m at SMI BL
(harm. #7 at ~6.5 mm gap, ~8.07 keV)



Spectral performance was ~fully restored by introducing -400 μm change in elevation (the IVU was re-aligned mechanically then).

IVU23 - 2.8 m at LiX BL
(harm. #9 at ~6.2 mm gap, ~9.24 keV



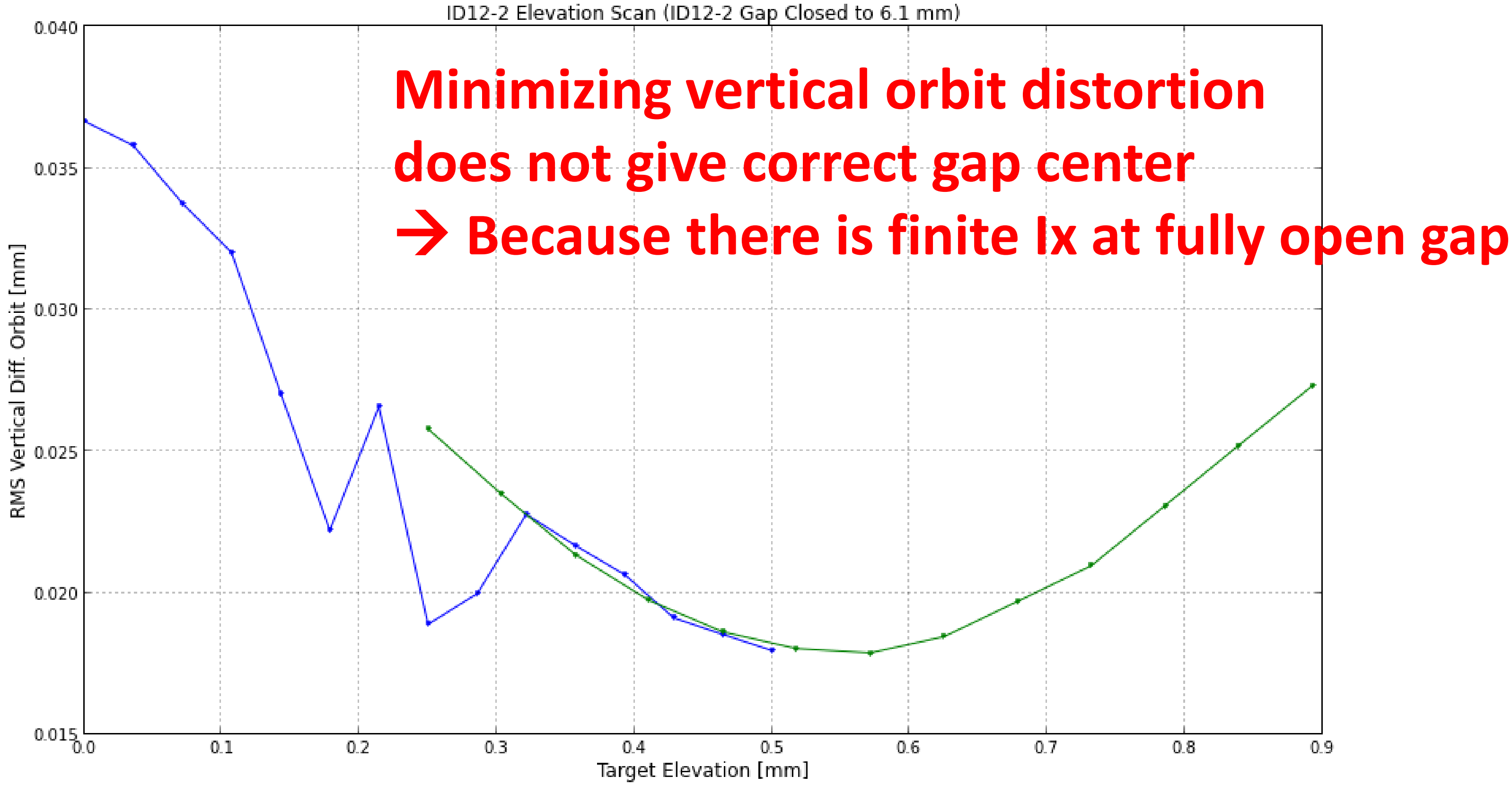
Spectral performance was significantly restored by introducing 30 μm change in taper (work is still in progress).

Spectral performance of ~Half of NSLS-II IVUs was restored / improved thanks to the Spectrum-Based Alignment procedure. **The "underperforming" IVUs are identified by comparison of their measured spectra with SRW simulations** (making use of magnetic measurements data).

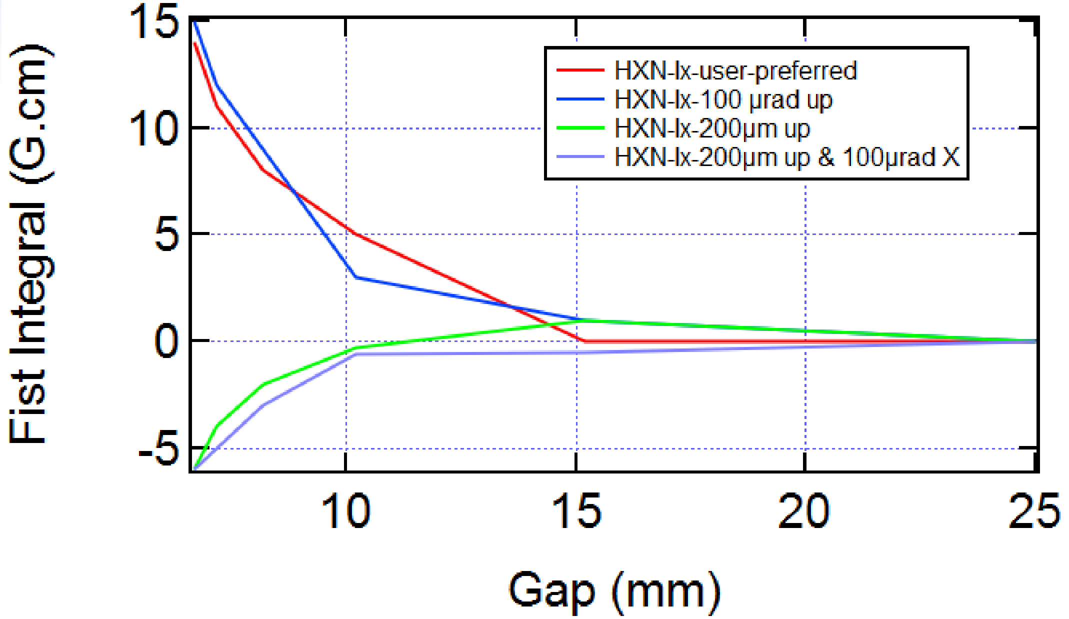
O.Chubar

Gap Center Search by E-Beam

- https://logbook.nsls2.bnl.gov/Operations/index.html#38760_1
- **yhidaka, 3/2/16, 8:57 am** Show details
- Elevation scan indicates that the optimal elevation for ID12-2 is +560 um. Note that the beam orbit was vertically off by +100 um. So, the ID needs to be raised by 460 um mechanically to align around BBA.



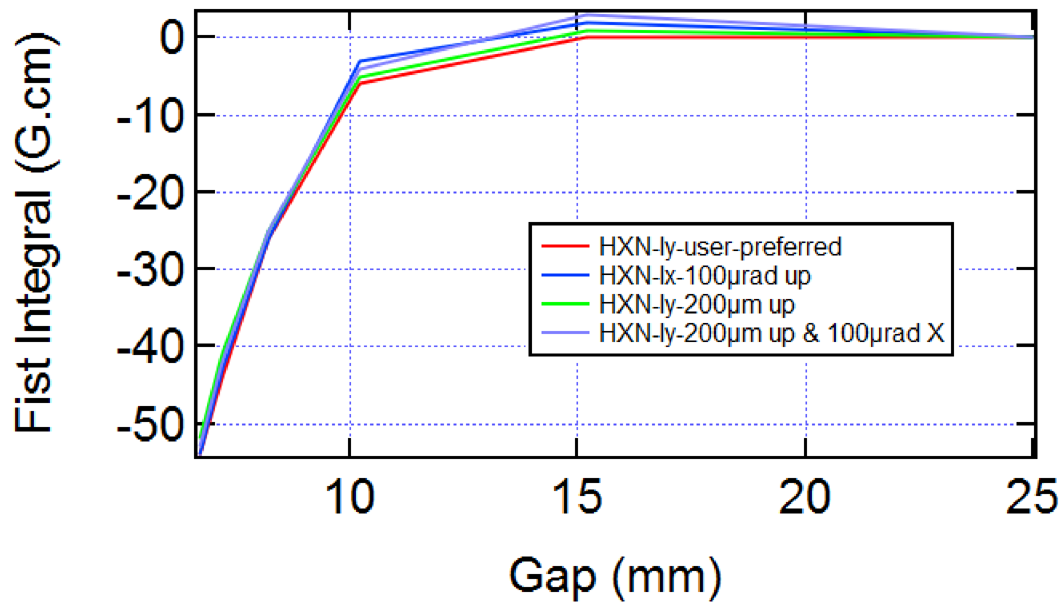
HXN (3-m IVU) with Beam Steering



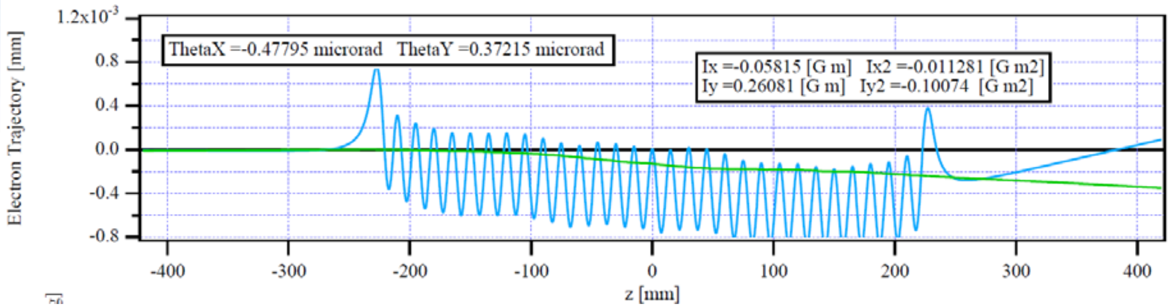
Original Orbit Set Values:
θx=+14 μrad
θy=-35 μrad

← Horizontal Field Integral Change
→ Sensitive to vertical translation
→ Insensitive to angle change

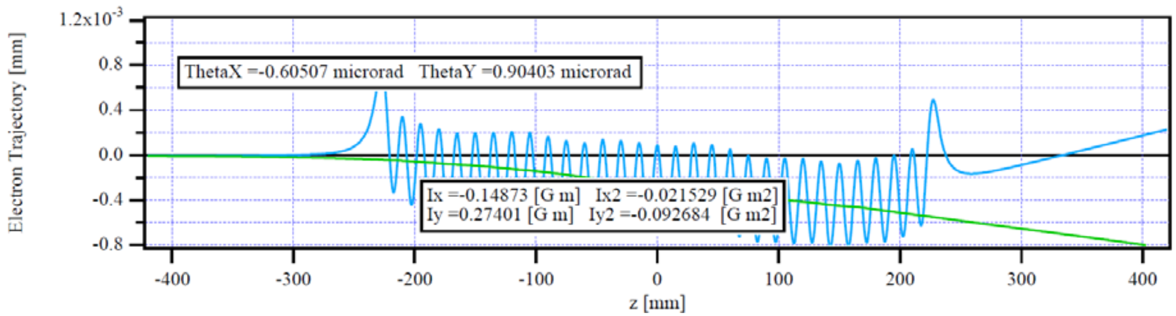
Vertical Field Integral Change →
→ Insensitive to both translation and angle change



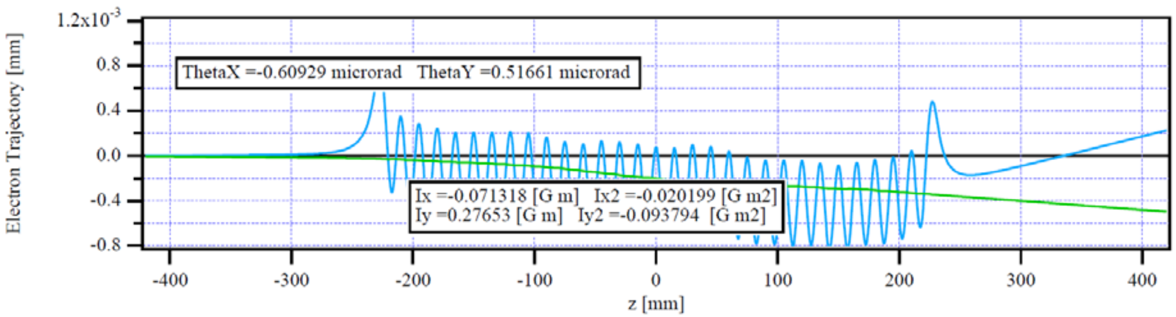
Effect of Vertical Translations/Angle (Calibration Array)



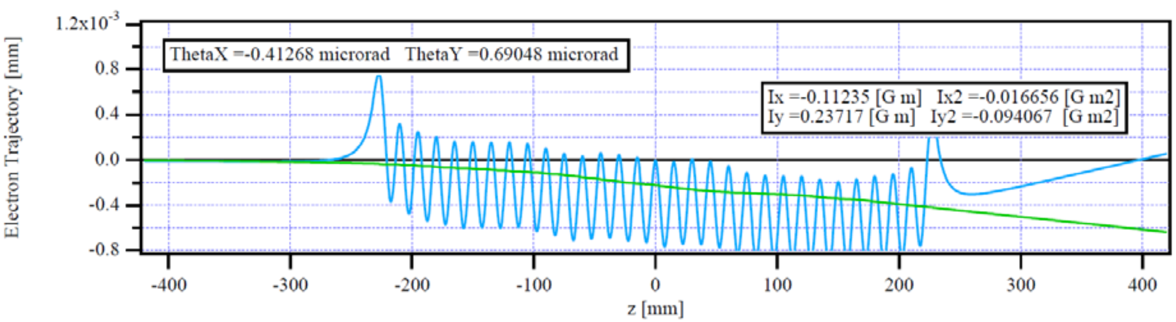
On-Axis:
Ix=5.8 G.cm, Iy=21G.cm
Ph.Err=1.6°



Y=+0.2mm:
Ix=14 G.cm, Iy=27G.cm
Ph.Err=1.6 °



Y=-0.2mm:
Ix=7.1 G.cm, Iy=28G.cm
Ph.Err=1.6 °



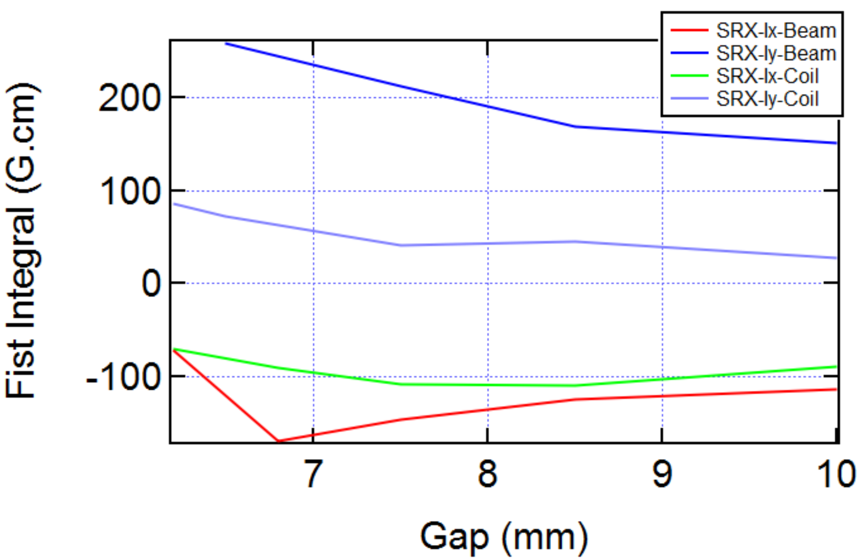
Y[Z=0]=0
Vertical Angle 0.2mrad:
Ix=11 G.cm, Iy=24G.cm
Ph.Err=3.2°

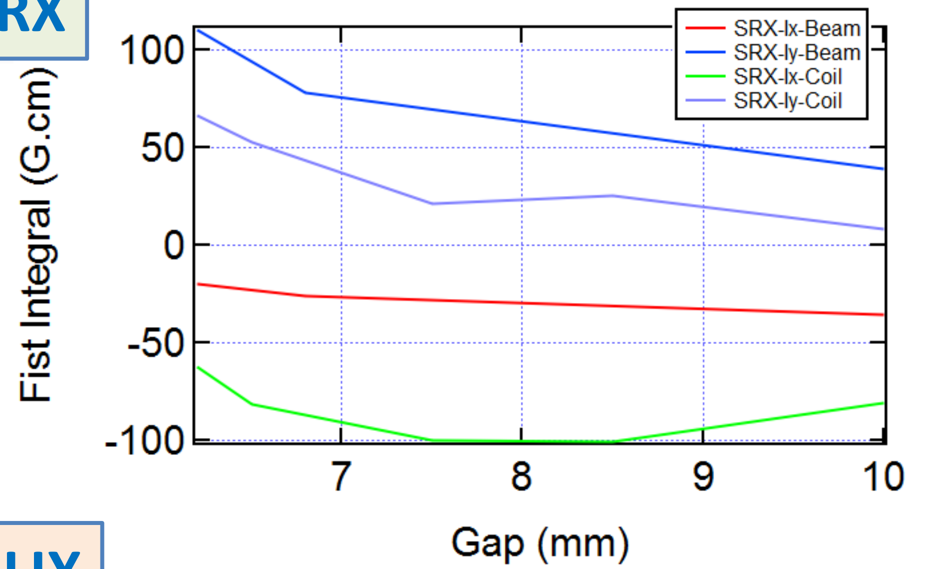
SRX (1.5-m IVU) & LIX (2.8-m IVU) Mag. Meas. vs Beam

Old Beam Data before Spectral Optimization

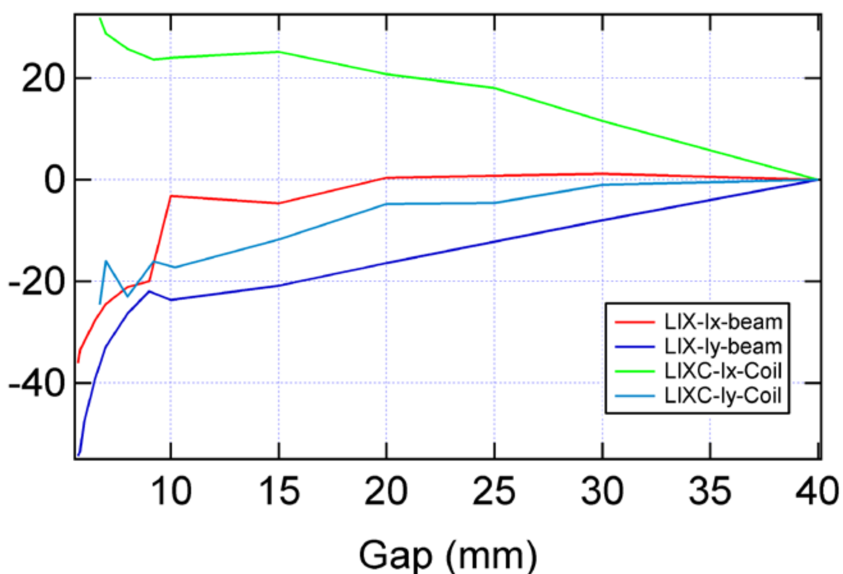
New Beam Data after Spectral Optimization

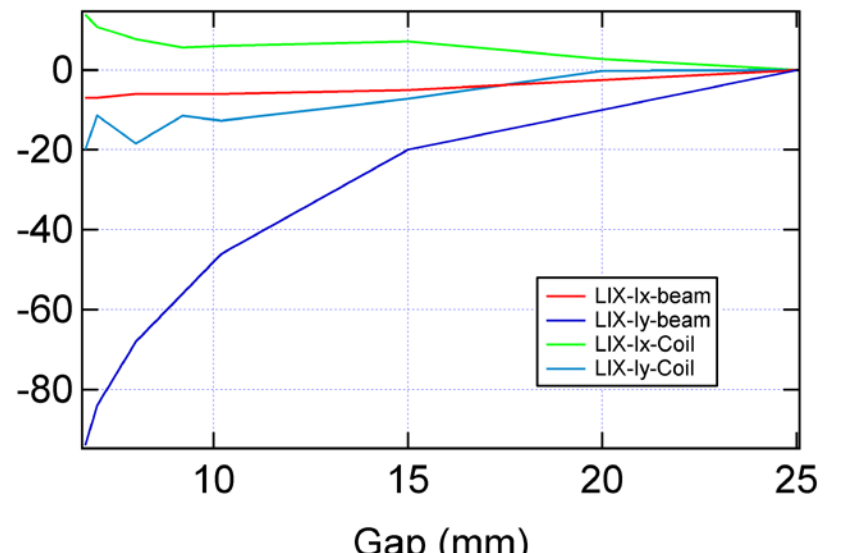
SRX



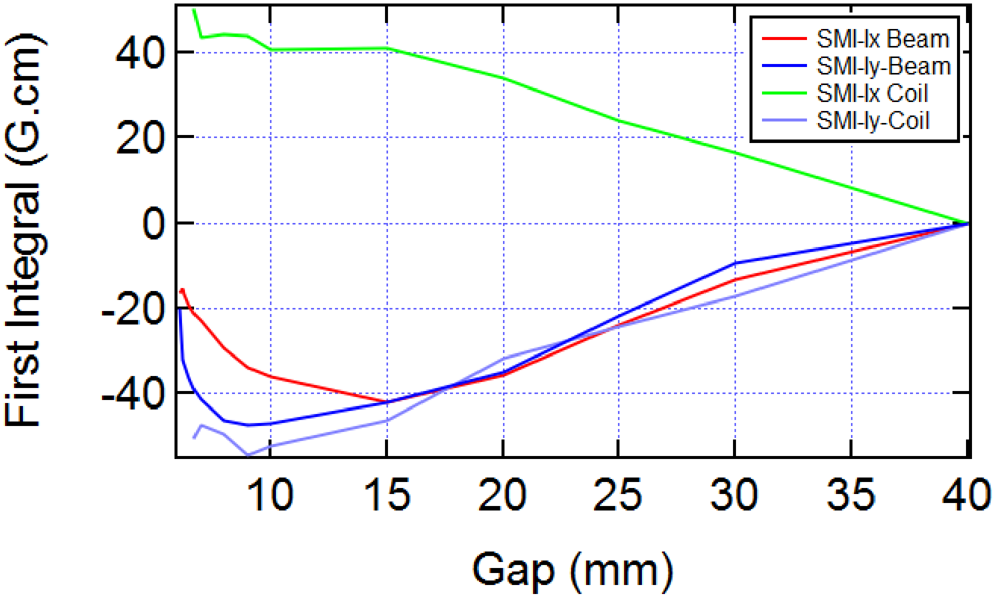


LIX



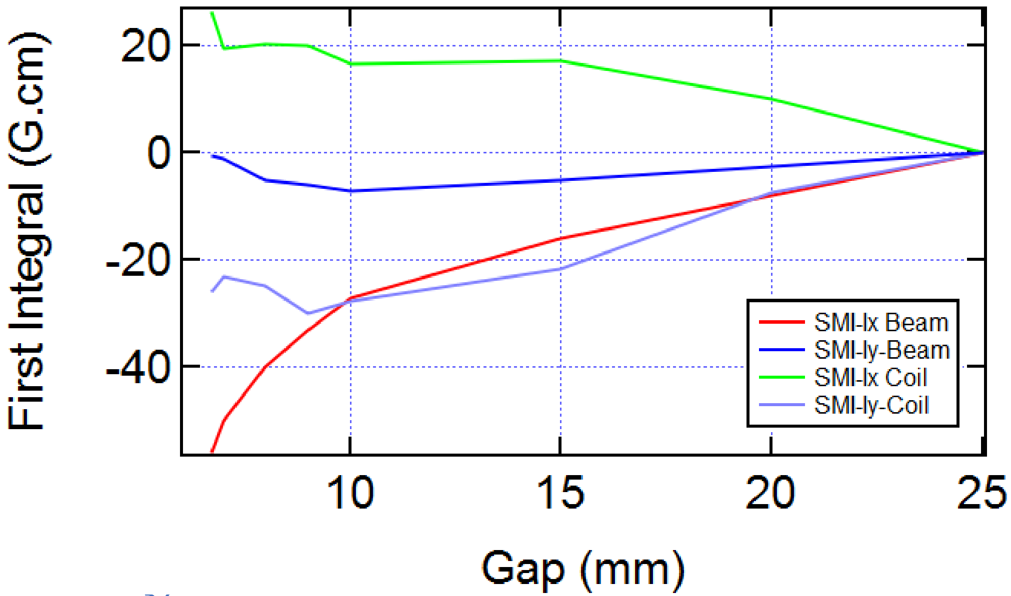


SMI (2.8-m IVU) Mag. Meas. Vs Beam

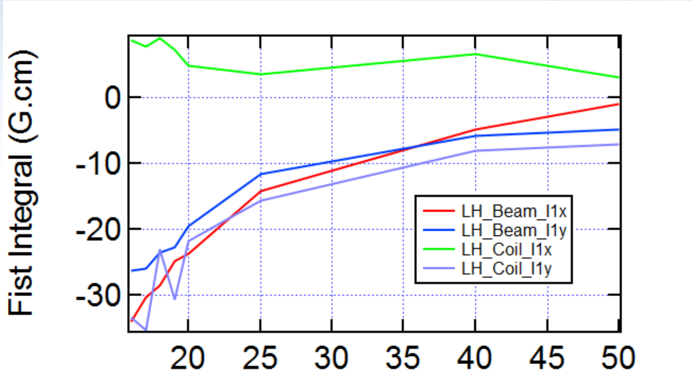


Old Beam Data Before Spectral Optimization
(beam with +100 mm vertical offset)

New Beam Data After Spectral Optimization

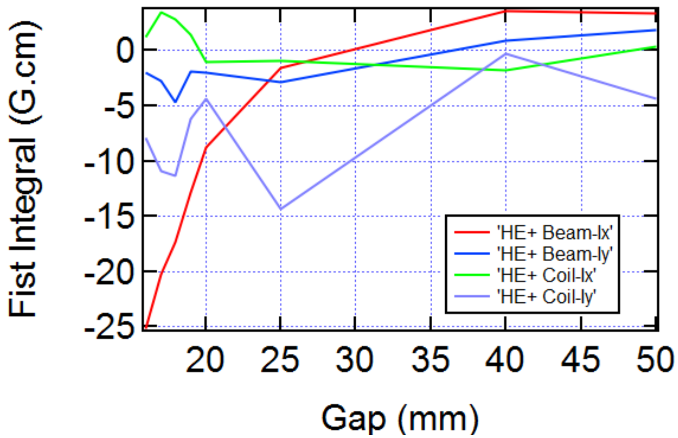


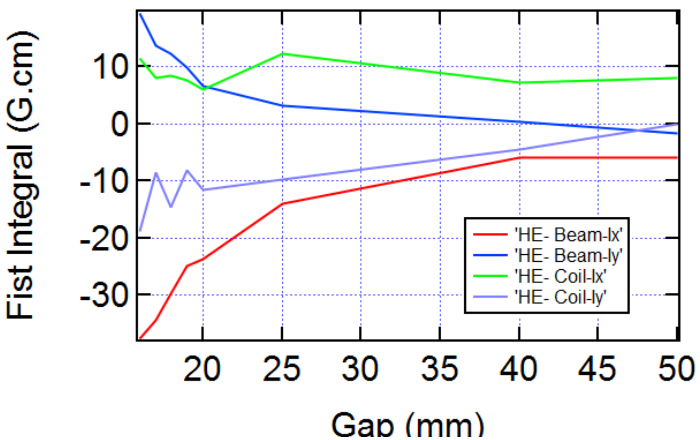
SIX (3.5m EPU) Mag. Meas. Vs Beam

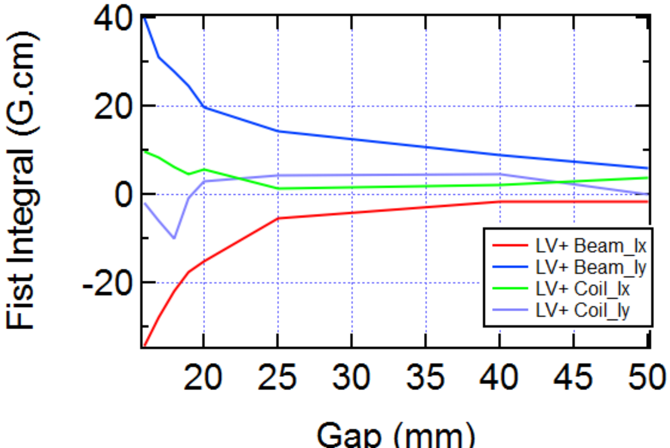


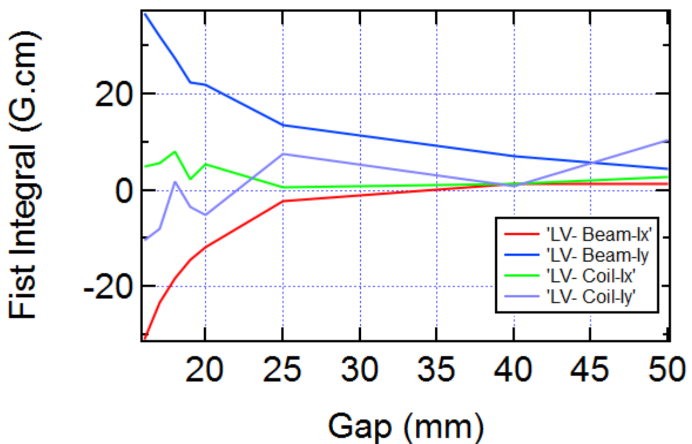
Integrated Field Integral variations with beam are larger than those by magnetic field measurement

→ **Spectral optimization may be still needed**





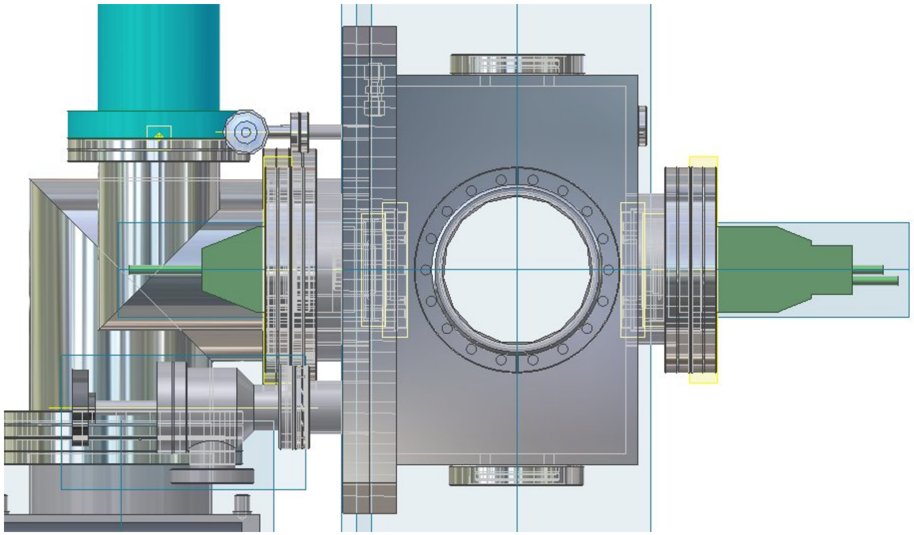


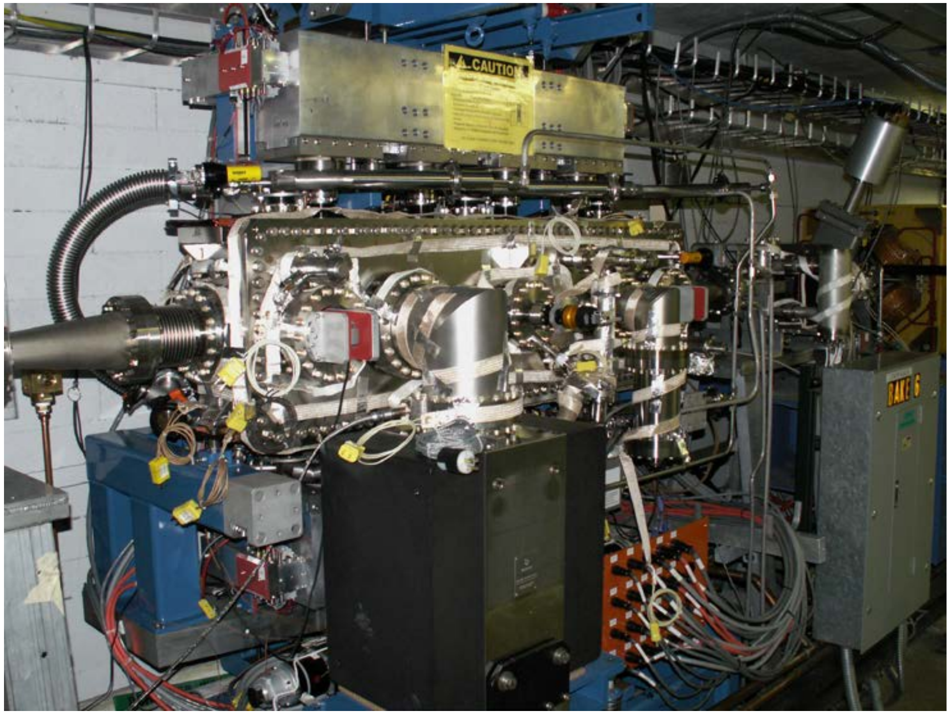


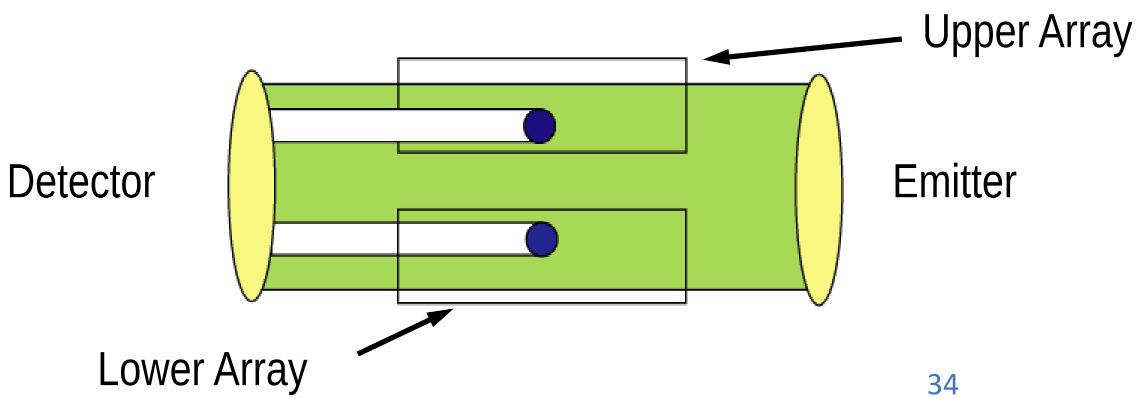
In-Situ Direct Gap Measurement Used in IVU18 (2005)

(Was not used for NSLS-II IVUs Due to their Larger Vacuum Chamber Size)

Measurement accuracy of $\pm 2\mu m$ and repeatability of $\pm 0.15\mu m$.

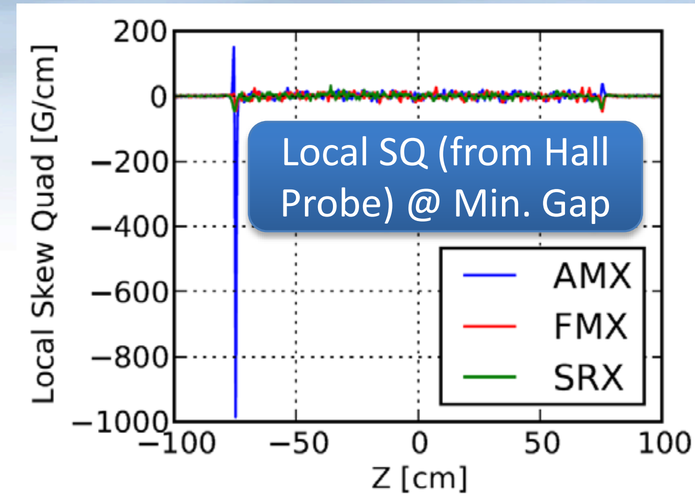






ID Coupling Correction

- SQ error estimates by DTBLOC (Driving-Terms-based Linear Optics Calibration) algorithm [**Y. Hidaka et al. NAPAC 2016**]
  - Based on RDTs formalism used by ESRF coupling correction [A. Franchi et al., PRSTAB 14, 034002 (2011)]
  - Also estimates normal quad errors as well as BPM gains/rolls/deformations (very important for coupling!)
  - Very fast (~2 min. data acq. [TbT + Dispersion], ~3 min. data proc. & fitting, for 1 iteration)



$$f_{\substack{1001\\1010}}(s) \cong \frac{\sum_w (\Delta a_2 L)_w \sqrt{\beta_x^w \beta_y^w}\, e^{i\left(\Delta\phi_x^{w,s} \mp \Delta\phi_y^{w,s}\right)}}{4\left(1 - e^{2\pi i (\nu_x \mp \nu_y)}\right)}$$

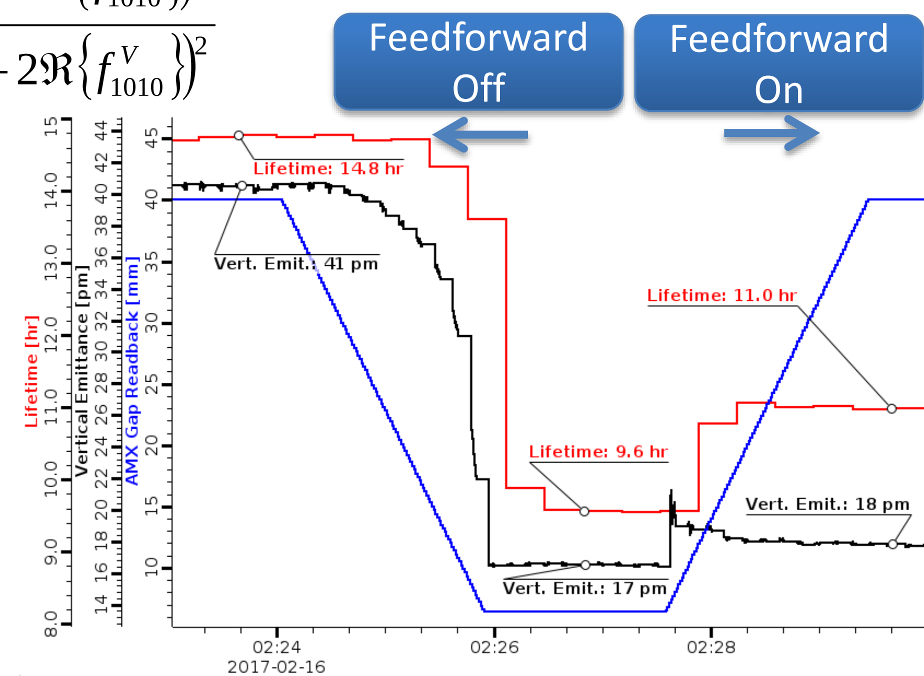
$$|f_{x1}| = \sqrt{2I_x\beta_{x0}} \qquad |f_{y1}| = \sqrt{2I_y\beta_{y0}}$$

$$\nu_x = 33.22, \nu_y = 16.26$$

$$|f_{x2}| = \sqrt{2I_y\beta_{x0}}\sqrt{\left(2\Im\{f_{1001}\} + 2\Im\{f_{1010}^H\}\right)^2 + \left(2\Re\{f_{1001}\} - 2\Re\{f_{1010}^H\}\right)^2}$$

$$|f_{y2}| = \sqrt{2I_x\beta_{y0}}\sqrt{\left(2\Im\{f_{0110}\} + 2\Im\{f_{1010}^V\}\right)^2 + \left(2\Re\{f_{0110}\} - 2\Re\{f_{1010}^V\}\right)^2}$$

- With feedforward turned on under a nominal user operation condition (i.e., high current, moderate emittance):
  - $\Delta\sigma_y$ of 60% (260% in ε_y) => 4% (8%)
  - Beam-current-lifetime-product change of 53% reduced to 11%.
- Table generated at low current (2 mA) (.207, .285) was equally effective at high current (250 mA).



Summary

- Magnetic measurement system at the NSLS-II has been cross-calibrated with other facilities' similar equipment.
- Some devices' characteristics had changed after transportation (may be due to mechanical shocks, extra baking process, variation in earth field?)
- EPU's 2nd order effect (dynamic integral effect) has been successfully compensated with current strips.
- Multipole measurement for small gap ID poses new challenge in terms of accuracy of measurement.
- Discrepancy between magnetic measurement and beam based one was larger with high field wiggler maybe due to:
  - Stronger focusing effect of wigglers, sensitive to vertical orbit centering
  - Large horizontal wiggling motion contributes increased path length.
- Beam-based measurement of horizontal field integral is more sensitive to beam orbit than that of vertical field.
- Beam-based kick measurement assumes straight trajectory inside an ID. However, magnetic measurements of some IDs show that some devices have somewhat curved trajectory in the ID.

More to do:

- More spectral optimizations for other IDs and repeat the same experiment
- Use long coils to straighten the trajectories in some IDs and repeat the same experiment
- Identify the sources of extra field in the tunnel

- Back up slides

Dynamic Aperture Considerations

•J.Benstsson 2007 ID review

- The impact of Insertion Devices (IDs) is given by

$$\langle H \rangle_{\lambda_u} = \frac{p_x^2 + p_y^2}{2(1+\delta)} - \frac{k_x^2 x^2 - k_y^2 y^2}{4 k_z^2 \rho_u^2 (1+\delta)} - \frac{k_x^4 x^4 + 3(k_x^2 - k_y^2) k_x^2 x^2 y^2 + k_y^4 y^4}{12 k_z^2 \rho_u^2 (1+\delta)} - \delta + O(p_{x,y})^4 \quad \text{(EQ 1)}$$

which drive beta and phase advance beat, tune shift, nonlinear resonances, and amplitude dependent tune shift. In particular

$$\Delta\nu_y = \frac{\beta_y L_u}{8\pi\rho_u^2}, \qquad \mathcal{M} = e^{:h:}\mathcal{M}_{\text{linear}}, \qquad \frac{\partial \nu_y}{\partial J_y} = \frac{\pi \beta_y^2 L_u}{4\lambda_u^2 \rho_u^2} \quad \text{(EQ 2)}$$

The beta and phase advance beat, and tune shift can be corrected locally.

- Top-up injection: stay-clear and efficiency.
- Touschek life time: momentum aperture, vertical physical apertures, and nonlinear dynamics.
- Impact on emittance: canting and Three-Pole Wigglers (~10% for 15 TPWs).

$$Min < \beta^2(s) > --> \beta_0 = L/2\sqrt[4]{5} \sim L/3$$

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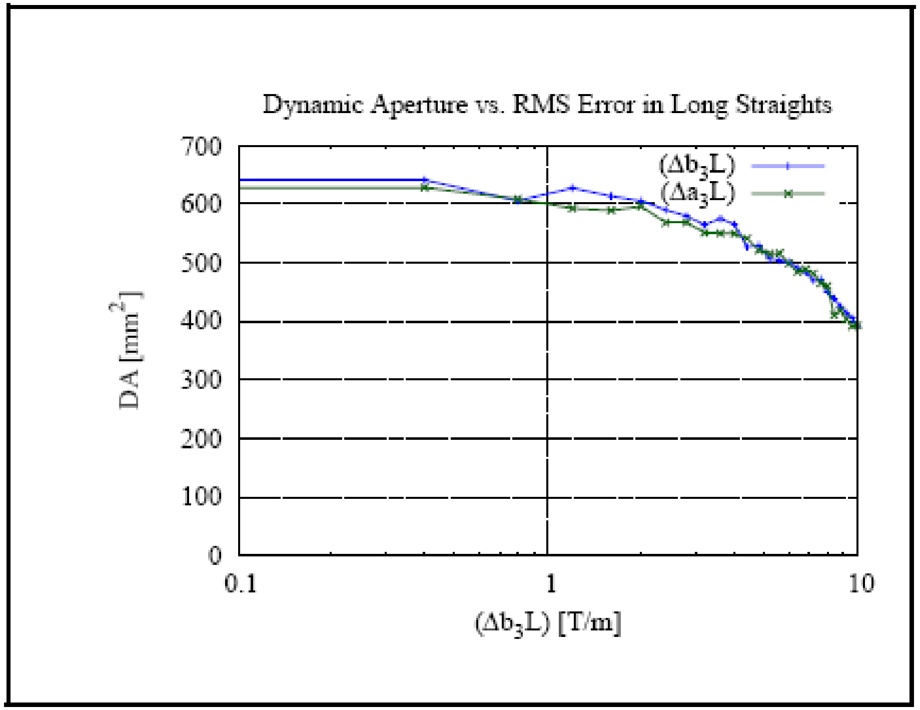
Impact of Radom Multipole Errors in the Long Straight

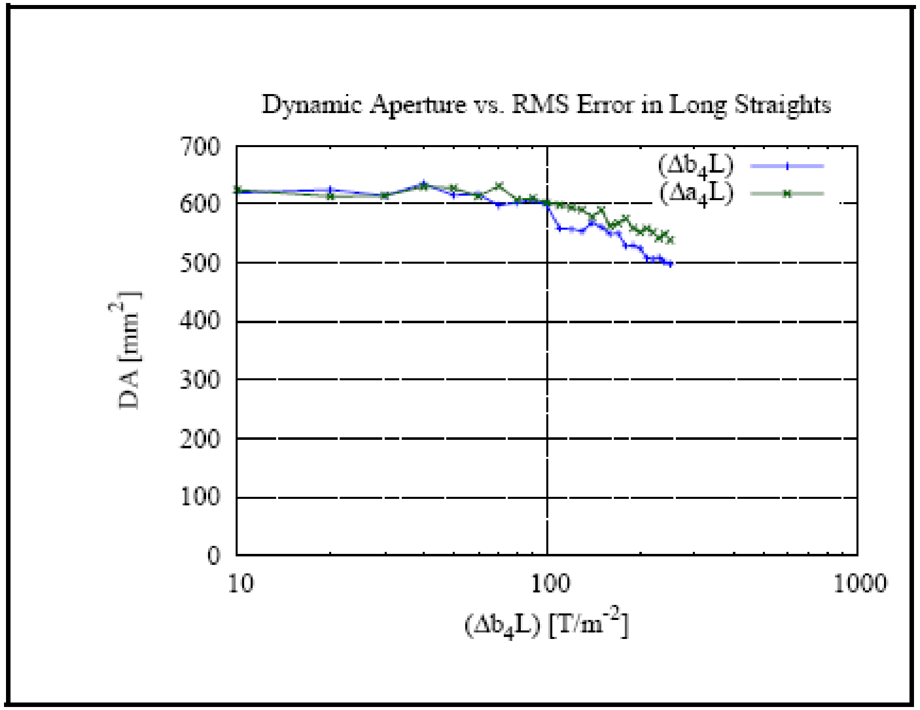
13 devices were used in the simulation

(J. Bengtsson)



Sextupoles

$$T/m = 100G/cm$$



Octupoles

$$T/m^2 = G/cm^2$$

A Typical "Canted" Short Straight