Current Status of NSLS-II Insertion Devices

Toshi Tanabe
ID Group Leader

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U.S. DEPARTMENT OF ENERGY | Office of Science
BROOKHAVEN NATIONAL LABORATORY

Outline

- Current Installation of Insertion Devices
- NSLS-II In-Vacuum Undulators (IVUs)
- HEX Superconducting Wiggler (on-going)
- Some Challenges to Overcome
  - Addition of Skew Quadrupole
  - HXN-IVU Repair
- Successful APPLE-II EPU Operation with Active Corrections
- Partner Beamline Devices
- Control System Upgrade
- Summery

Acknowledgement:

ID group members: D. Hidas, M. Musardo, J. Rank, D.A. Harder, P. Cappadoro, T. Corwin and C. Rhein

Part-time members: O. Chubar , C. Spataro and J. Escallier

Accelerator Physics: Y. Hidaka, A. Blednykh and Y. Li

Vacuum Group: Charles Hetzel and Charles De La Parra

Various Beamline Group Members

NSLS-II Insertion Devices Current Installation

- 2 x 3.0m-IVU20s
- 1 x 3.0m-IVU22 (Long Straight)
- 3 x 1.5m-IVU21s (two for canted configuration)
- 2 x 2.8m-IVU23s (canted : LS)
- 1 x 2.8m-IVU23 (LS)
- 1 x 1.0m-IVU18 (canted)

- 6 x 3.4m-DW100s (LS)
- 2 x 2.0m-EPU49s
- 1 x 2.8m-EPU105 and 1 x 1.4m-EPU57 (in-line configuration)
- 1 x 3.5m-EPU57 (LS)
- 1x1.6m-U42 and 1x 1.0m-EPU60 (canted)

3m-IVU22 for IXS beamline

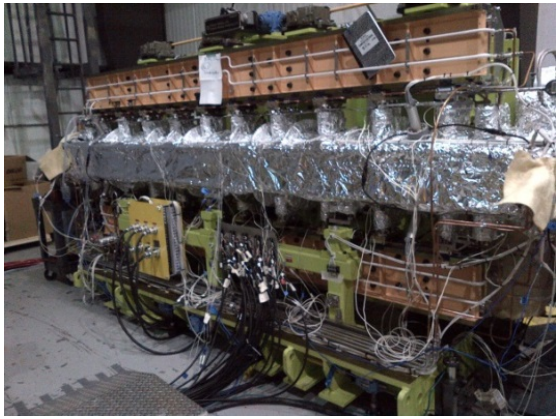
3.4m Damping Wigglers in tandem configuration

NSLS-II In-Vacuum Undulators

- Hybrid arrays with period length from 18 to 23mm
  - With movable gaps down to 5 mm
  - Bakeable to ***< 100°C***
- 4-m rectangular flanges for field mapping, ***sealed with 1 mm φ Al wires***
  - Some effort to achieve leak tightness
  - $\Delta T < 3^{o}C$ at flanges during bakes
- All successfully baked and achieved 10^{-10} Torr.

Installed Refurbished 1m IVU18

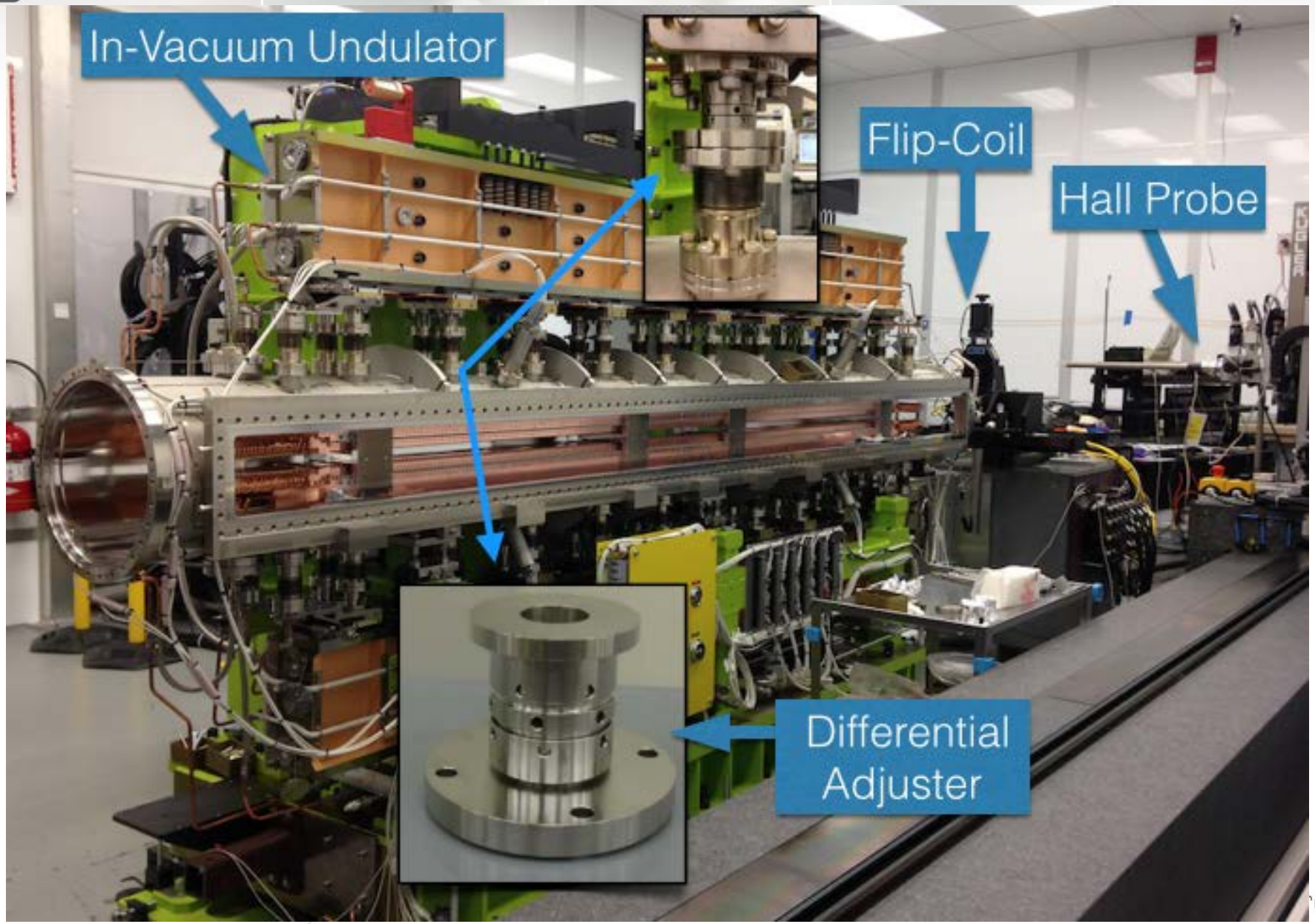
Field mapping



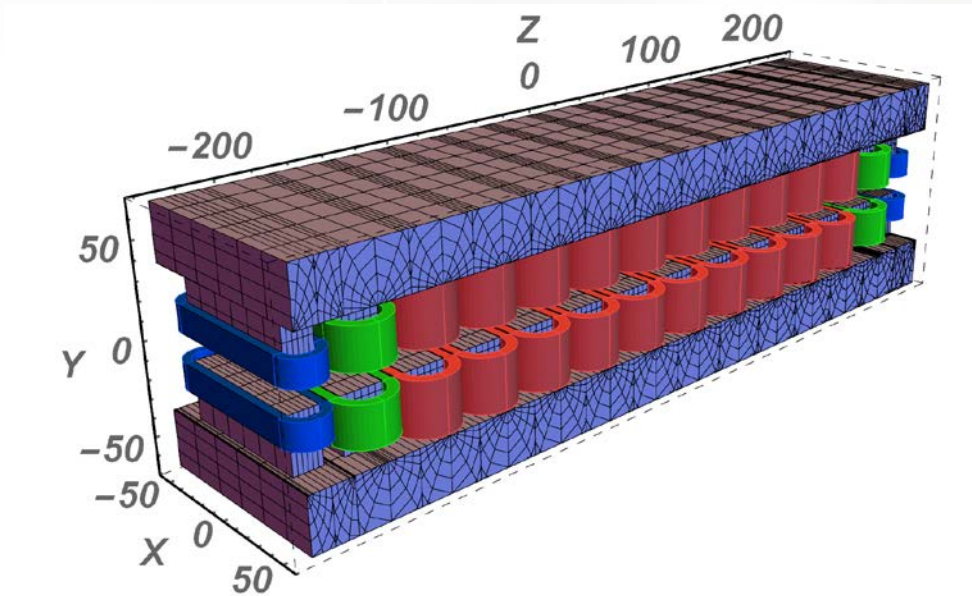
IVU bakeout

Installed 3m IVU20

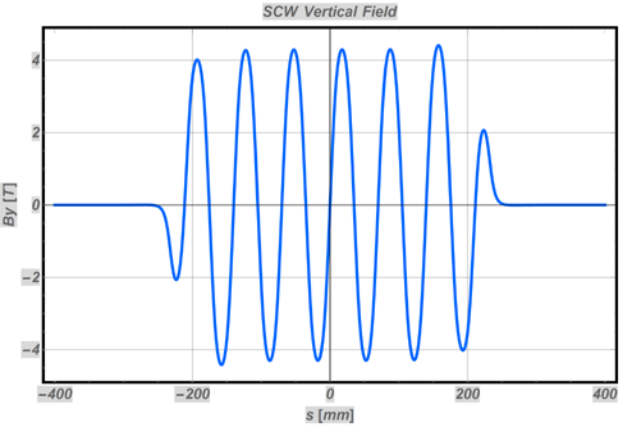
In-Vacuum Undualtor with a "Side Window"

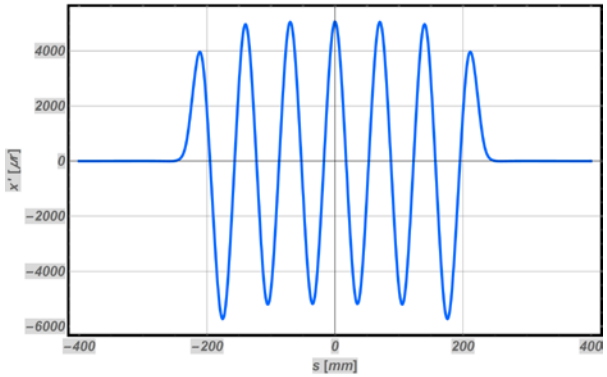


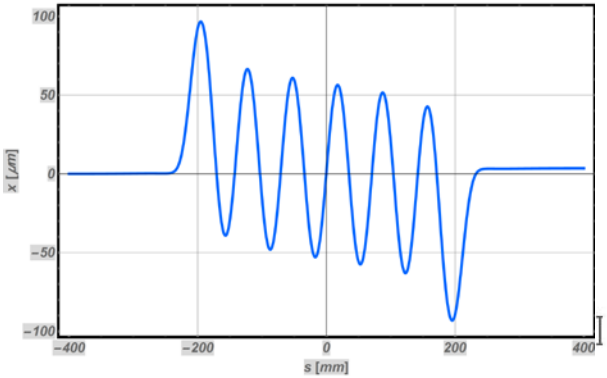
HEX-SCW Reference Design (10 pole Model)



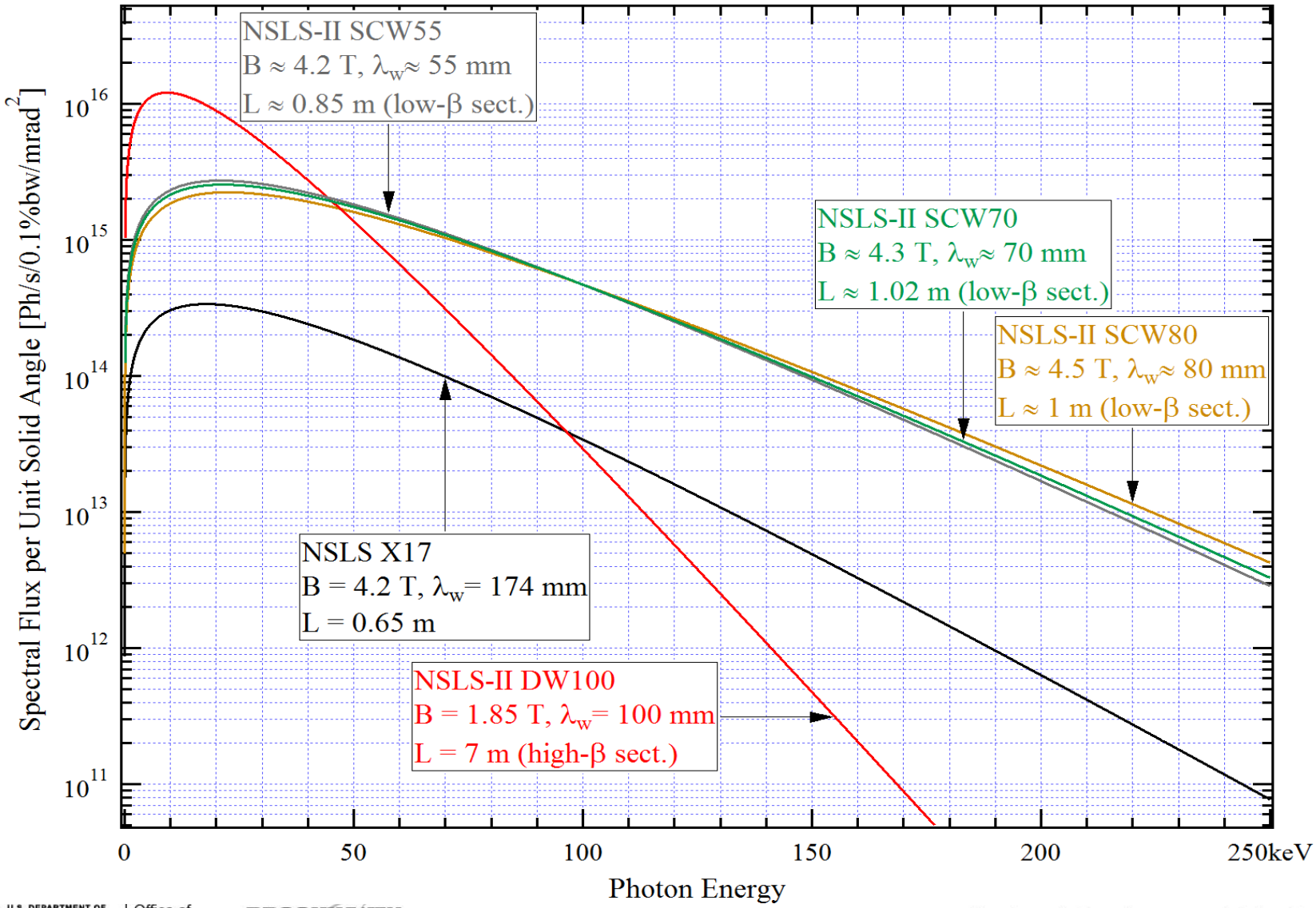
Magnetic Length	1.2m nominal (29 main and 4 partial poles)
Period: nominal	70 mm
Yoke Gap	15.2 mm
Peak field: nominal	4.3 T
Pole width	80mm
Main (red) Coil Height	29.5mm
Main Coil Thickness	6.3mm
Main Yoke Thickness	22.4mm
End Yoke Thickness	14.336mm
Green Coil Height	22.125mm
Blue Coil Height	14.16mm
Yoke Material	1006 Steel
Nominal Engineering Current Density@4.3T	900A/mm^2







HEX-SCW Spectra



Some Challenges to Overcome

- NSLS-II ID is optimized for each beamline requirement. Therefore, there are currently ***13*** different types to maintain.
- Three used devices for partner beamline (NYX-U18, SST-U42 and SST-EPU60) have been installed. They require different spare parts and maintenance activities.
- Many spare parts are still lacking due to many types of parts, especially vacuum and mechanical parts.
- HXN-IVU suffered from catastrophic failure and the beamline was disabled for 6 months. The device was successfully repaired in house.
- SQ coils have been added to one slow corrector to compensate excessive coupling change due to AMX-IVU gap motion.
- Control system for Neomax IVUs has been successfully updated in house.

SQ Issues

- 03/18/2016:
  - First (?) observation of lifetime jump with AMX (C17-1) gap changes during user operation (8.1 hr => 9.0 hr when gap changed from 40 mm to 7 mm) [https://logbook.nsls2.bnl.gov/Operations/#39281_2]

6/28/2016 (Bare)	Lifetime [hr]	Ratio [%]
All IDs Open	13.54 ± 1.33	N/A
Only SRX @ 6.4 mm	13.21 ± 1.15	98 ± 13
Only AMX @ 6.4 mm	56.05 ± 8.92	414 ± 77
Only AMX @ 7.0 mm	46.33 ± 4.12	342 ± 45
Only LIX @ 5.7 mm	19.27 ± 1.44	137 ± 14
All IDs Open	14.02 ± 0.98	N/A

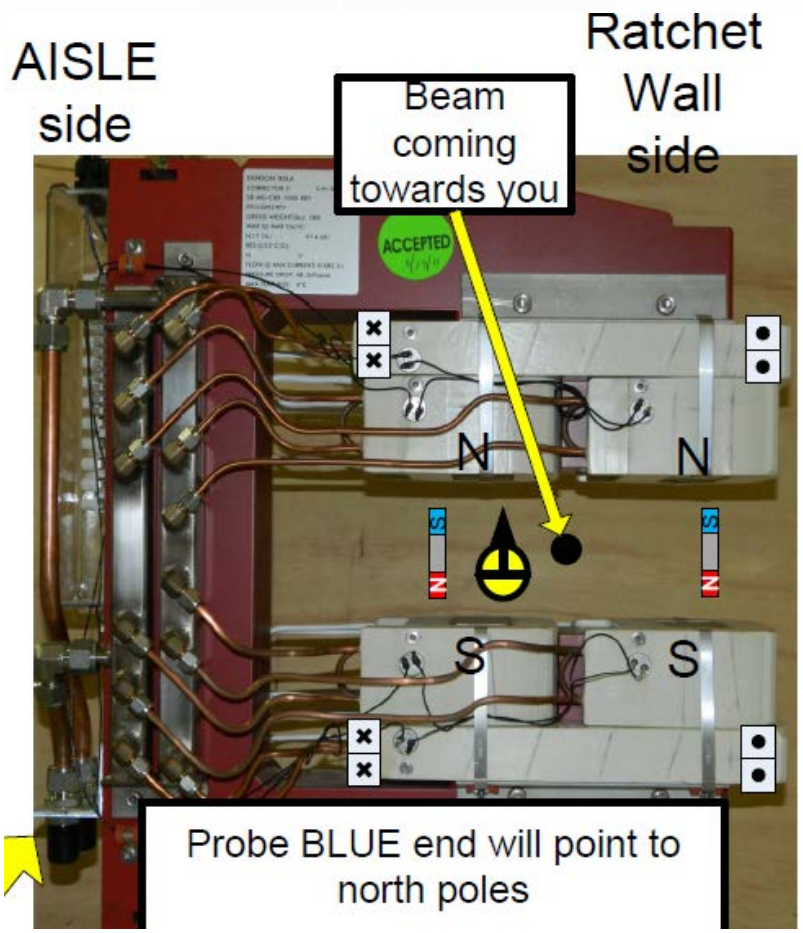
8/9/2016 (Bare)	Lifetime [hr]	Ratio [%]
All IDs Open	10.94 ± 0.75	N/A
Only FMX @ 6.4 mm	13.52 ± 0.89	124 ± 12
Only AMX @ 6.4 mm	35.71 ± 2.84	326 ± 34

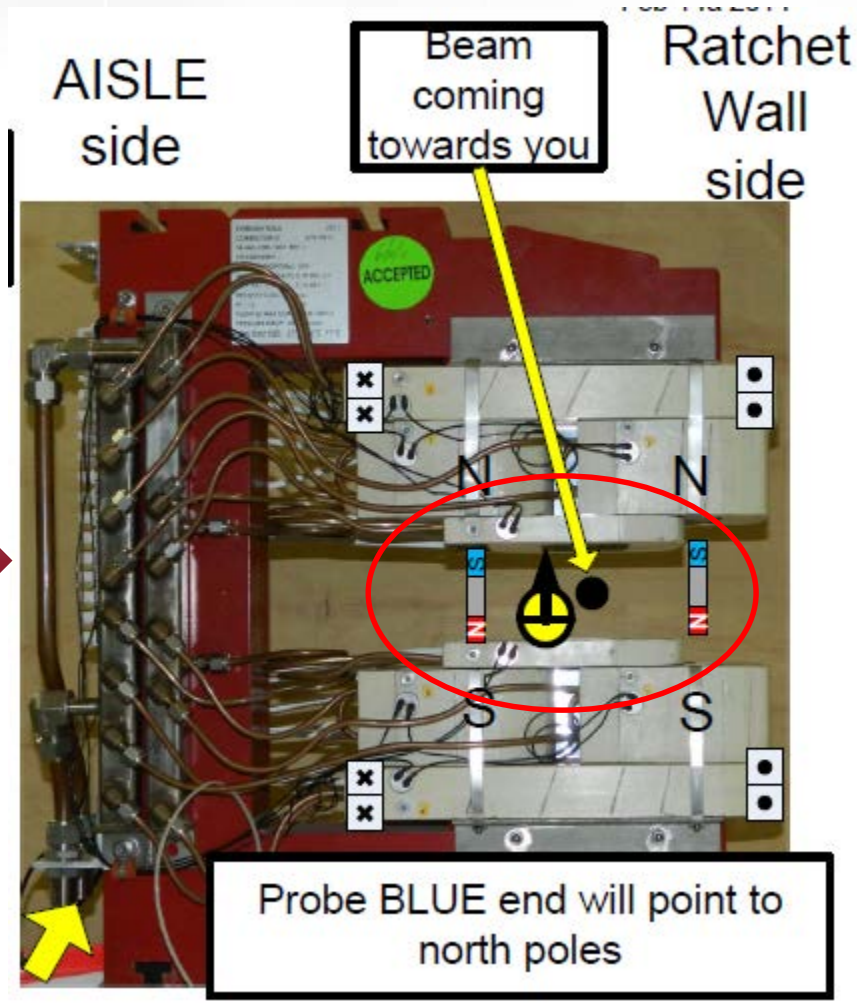
8/8/2016 (Bare, All IDs open)	Lifetime [hr]	Ratio [%]
Skews On (1.76 mA in Buckets 1-100)	10.36 ± 0.88	N/A
Skews Off (1.74 mA in Buckets 1-100)	64.60 ± 6.77	624 ± 84

- Lifetime relative change from lattice with well-corrected coupling & vertical dispersion:
  - SRX: no change
  - FMX: 24% increase
  - LIX: 37% increase
  - AMX: ~3.5x increase
  - w/o Ring Skews: ~6x increase

* SRX = C05; AMX = C17-1; FMX = C17-2; LIX = C16

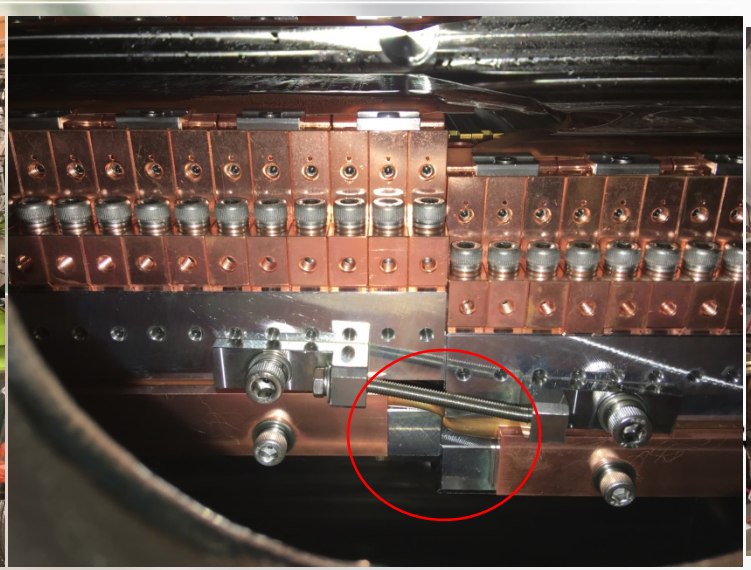
Adding SQ Coils to One of Slow Correctors

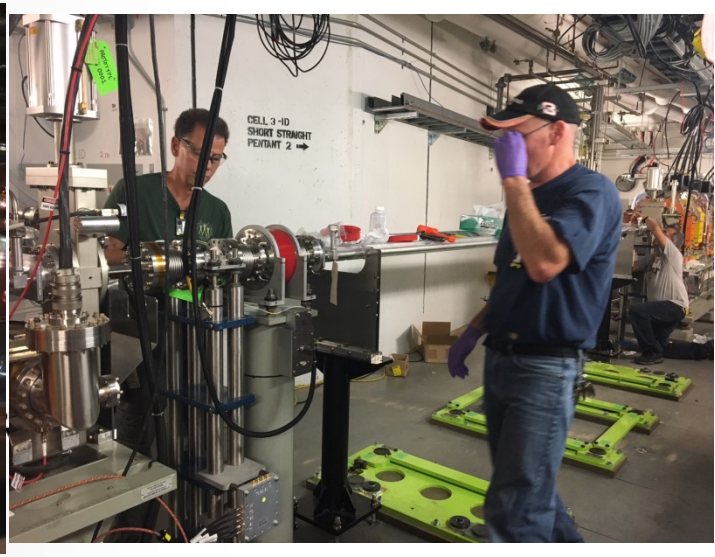




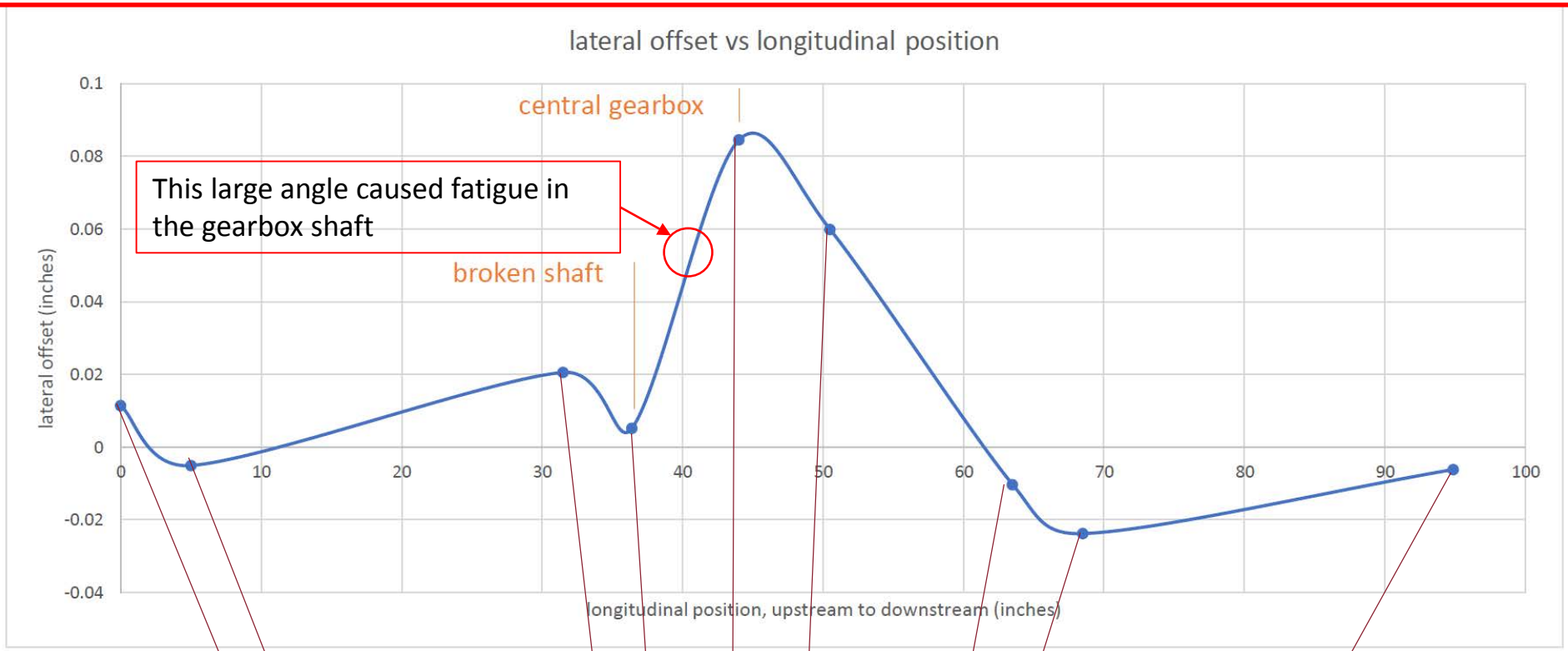
HXN (C3)-IVU Incident

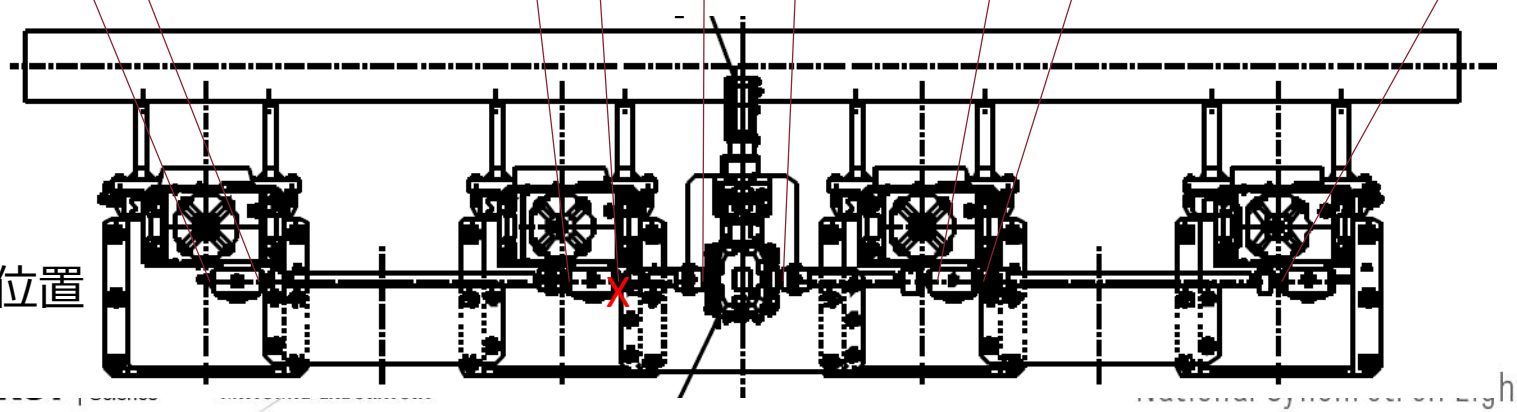
- Just after midnight (0:08) on 7/1/2018, C3-IVU gap stopped responding. Soon after (0:11) gate valves around the straight closed. Operator stopped water at 2:23am.
- With truly commendable effort by all the ASD groups, the device was uninstalled and the straight was back to operation with only 30 hours of loss of operation.
- The device was transported to ID-MMF (bldg. 832) for repair.
- The device is now back in operation and no degradation of performance was observed.





It was determined that the primary root cause of the gearbox shaft failure at Cell 3 is misalignment of the drivetrain. It was likely to be created during transportation.





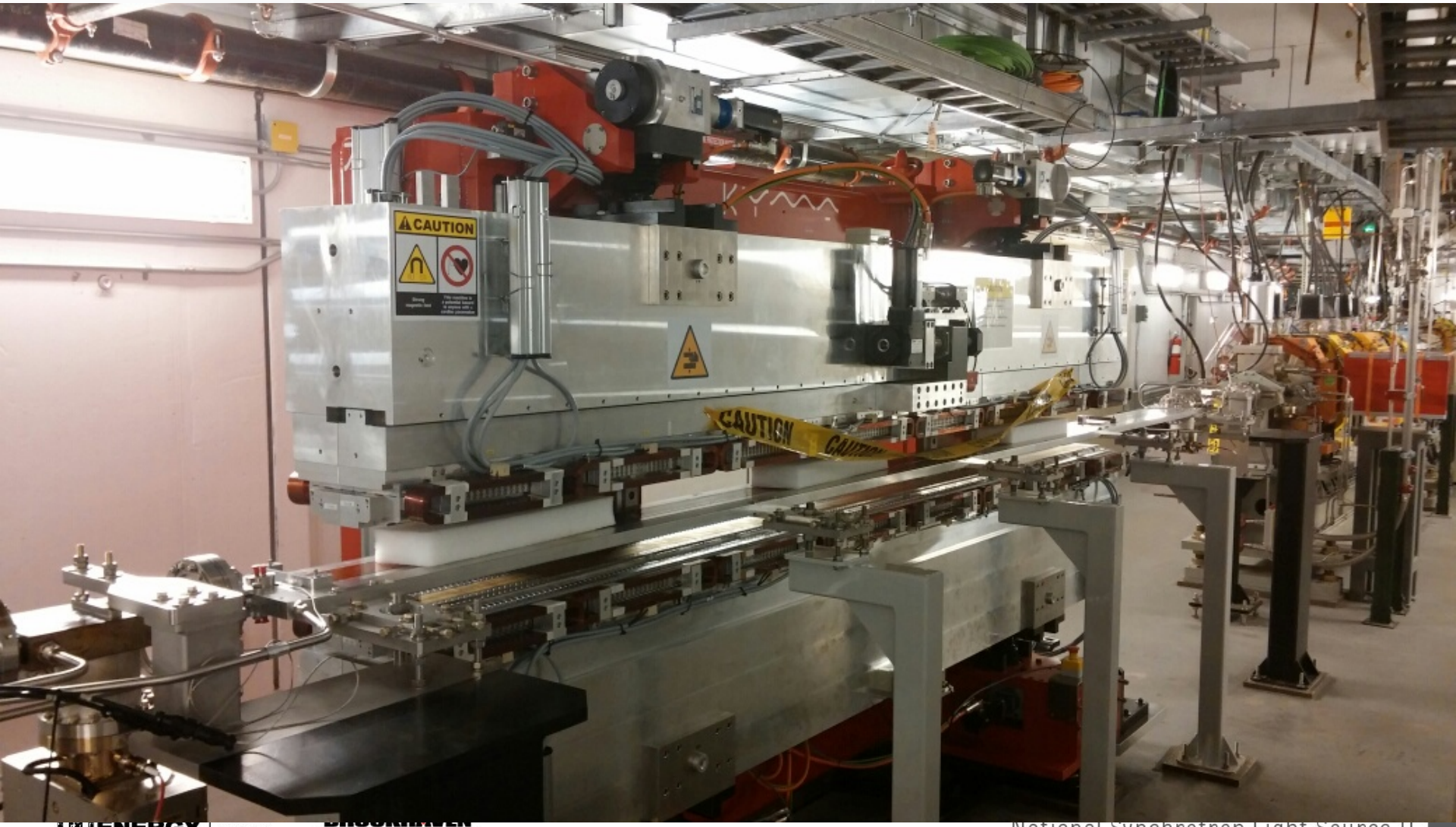
各測定位置

- Successful APPLE-II EPU Operations with Active Corrections

o 3.5m-EPU57

o 1.4m-EPU / 2.8m-QEPU105

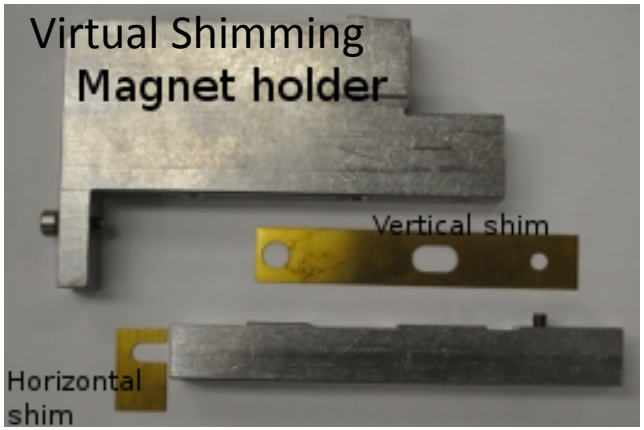
3.5m-SIX EPU57 (16mm Min Gap w. Current Strips)

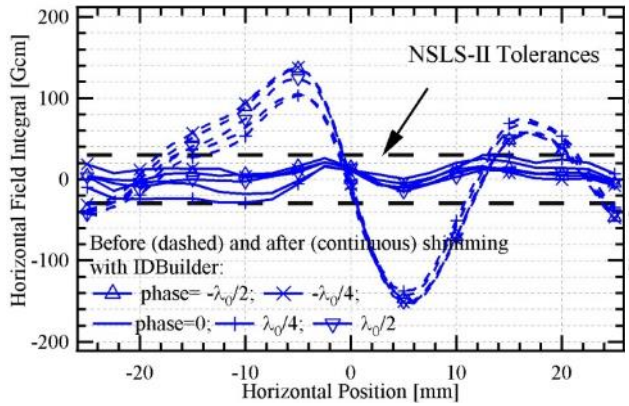


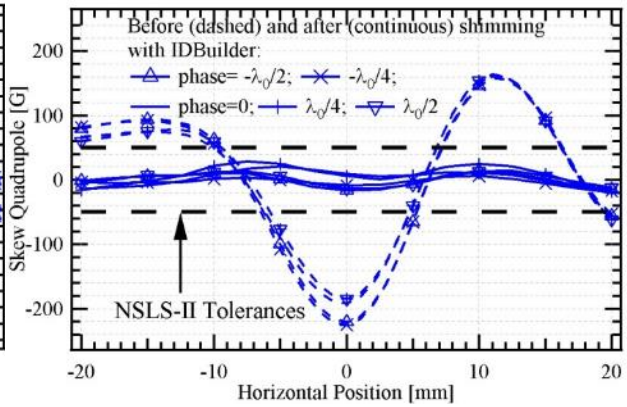
1.4m-EPU57 & 2.7m-QEPU105 in Tandem Config. (16mm Min Gap w. Current Strips)

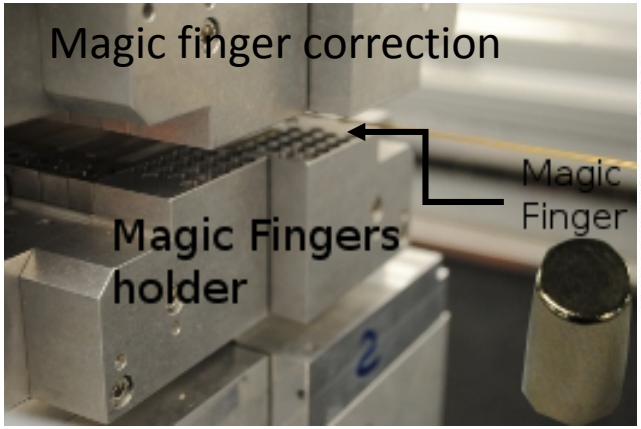
3.5m-SIX EPU57 Tuning Results

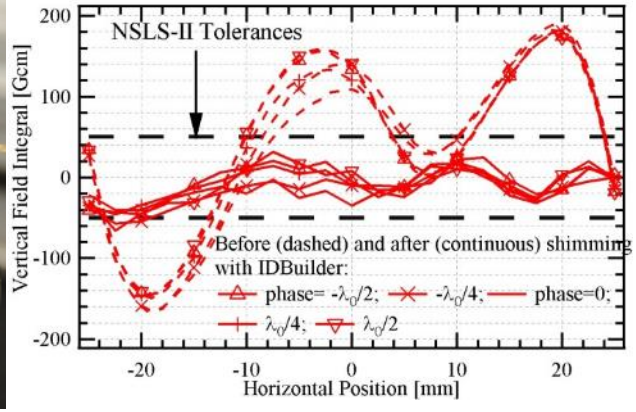
- In-house shimming using ***IDBuilder*** successfully completed in August 2016

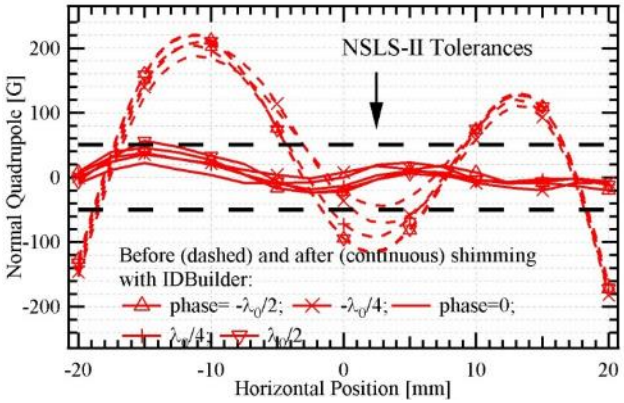






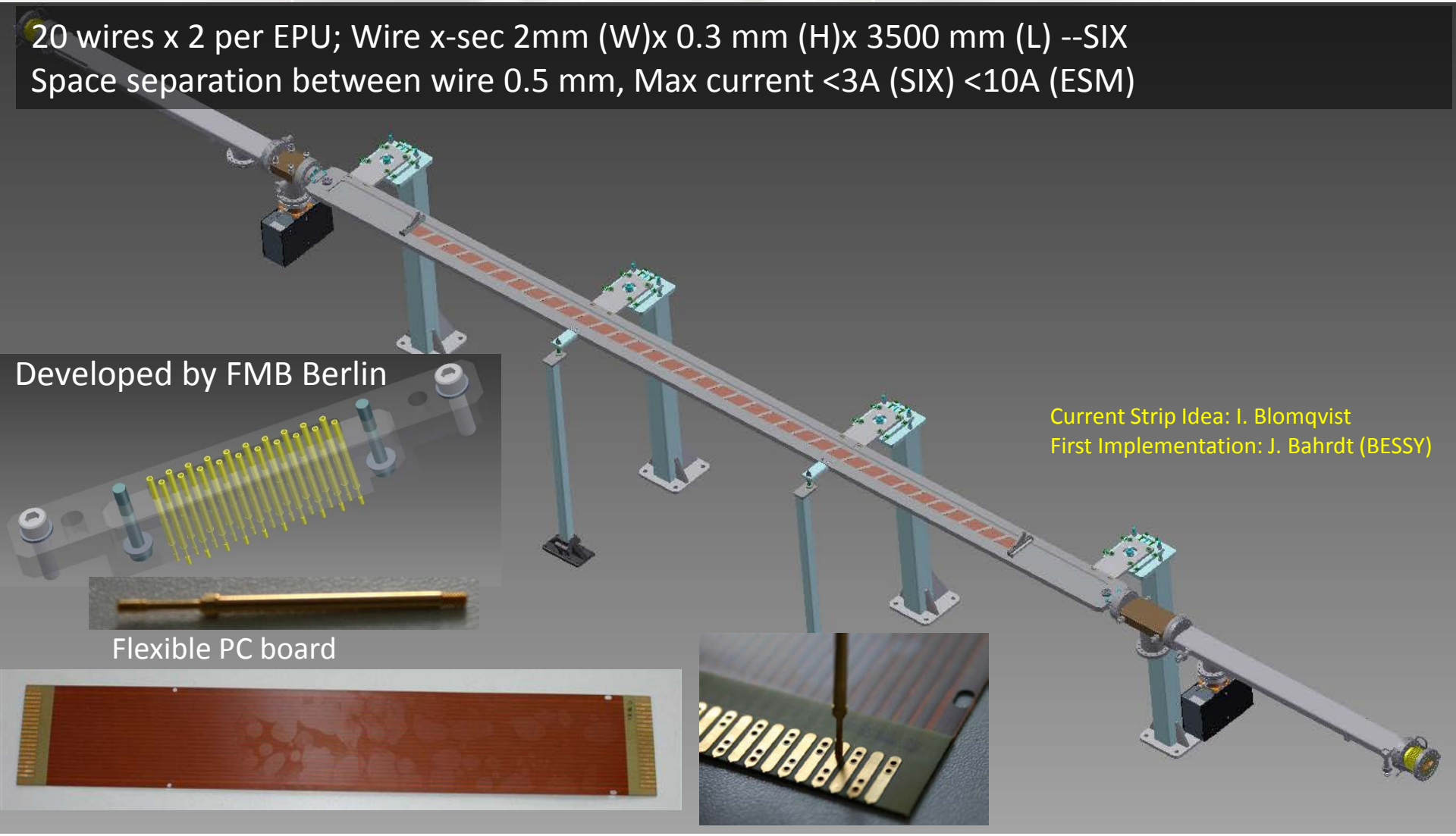




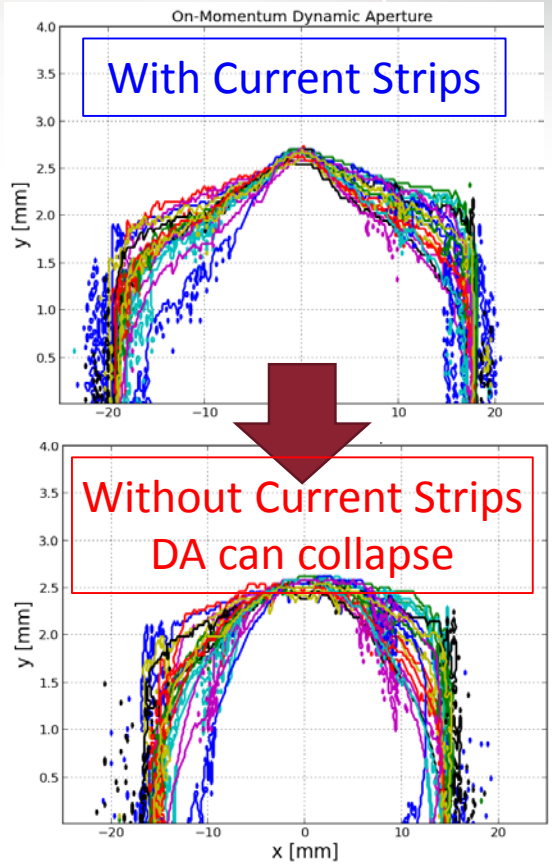


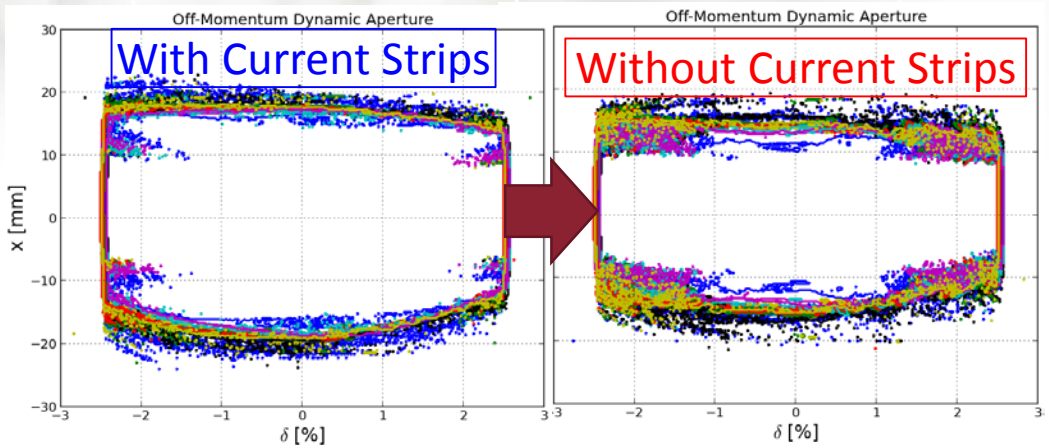
NEXT EPUs Current Strips for 2nd-Order Kick Correction

20 wires x 2 per EPU; Wire x-sec 2mm (W)x 0.3 mm (H)x 3500 mm (L) --SIX
Space separation between wire 0.5 mm, Max current <3A (SIX) <10A (ESM)



2nd-Order Kick Impact from EPUs on Beam Dynamics

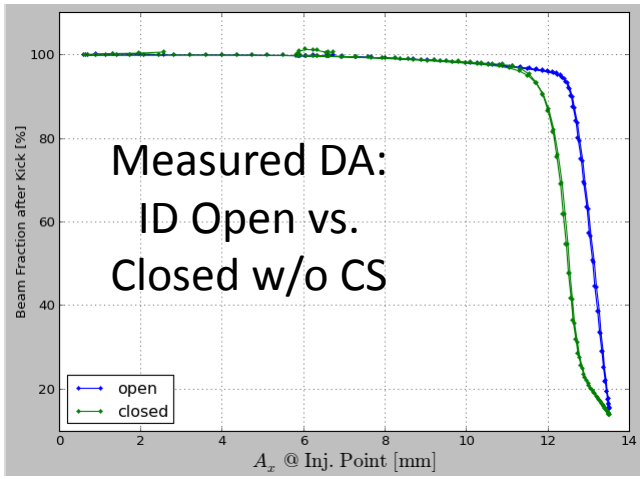




SIX @ 16 mm gap & 28.5 mm phase (Linear Vertical Mode)

On-Axis Tune Shift w/o CS

	Measured	Expected
$\Delta\nu_x$	-0.01241	-0.01302
$\Delta\nu_y$	+0.00403	+0.00405

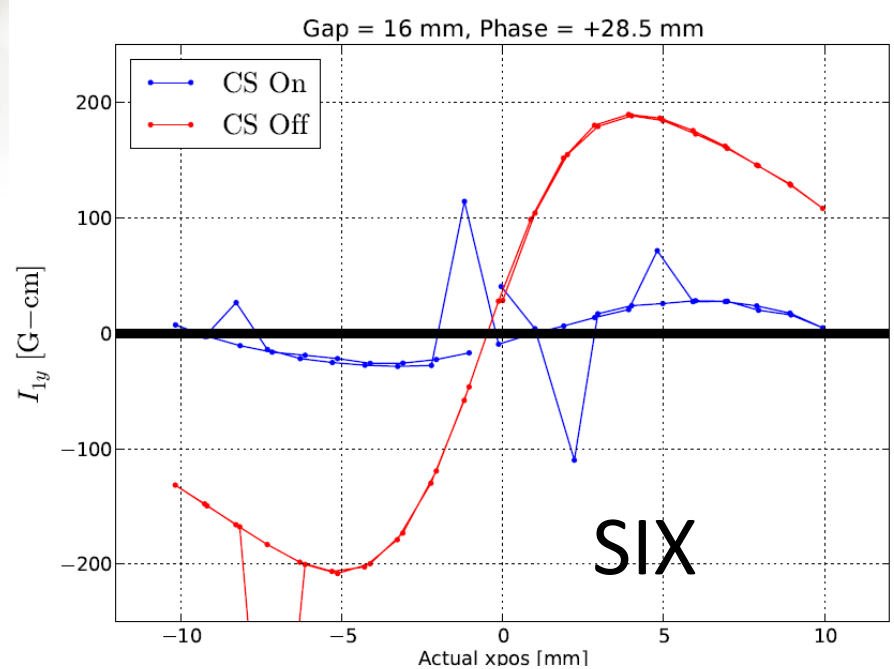


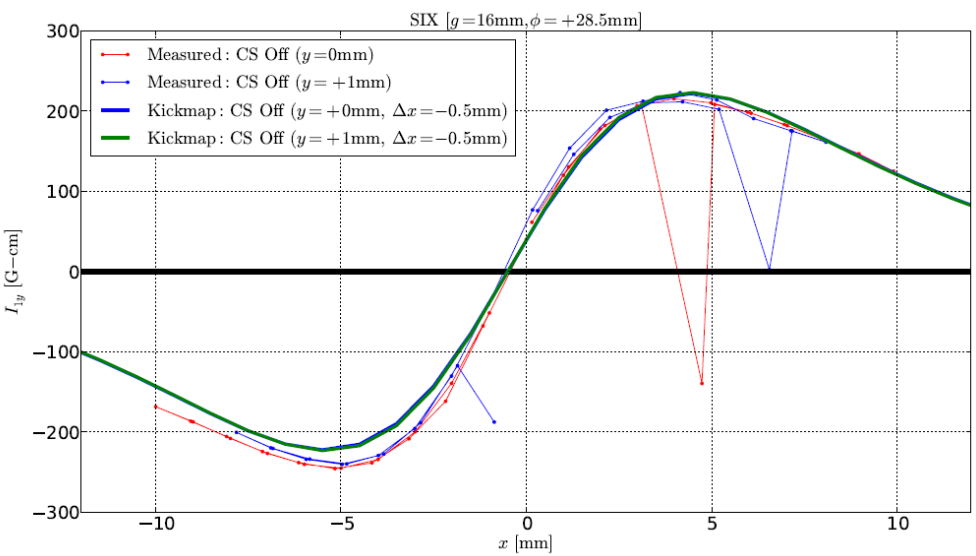
Y. Hidaka

Direct Meas. & Correction of 1st and 2nd-Order Kicks

- Utilize same technique used in orbit feedforward table generation to measure beam-based field integrals with different horizontal orbit bumps.
- Compensation confirmed for SIX (But only 70% expected correction applied)

	Peak 1st Fld. Int.	Inj. Eff. [%]
Without CS	~200 G-cm	70.7±11.5
With CS	~20 G-cm	96.1±3.8

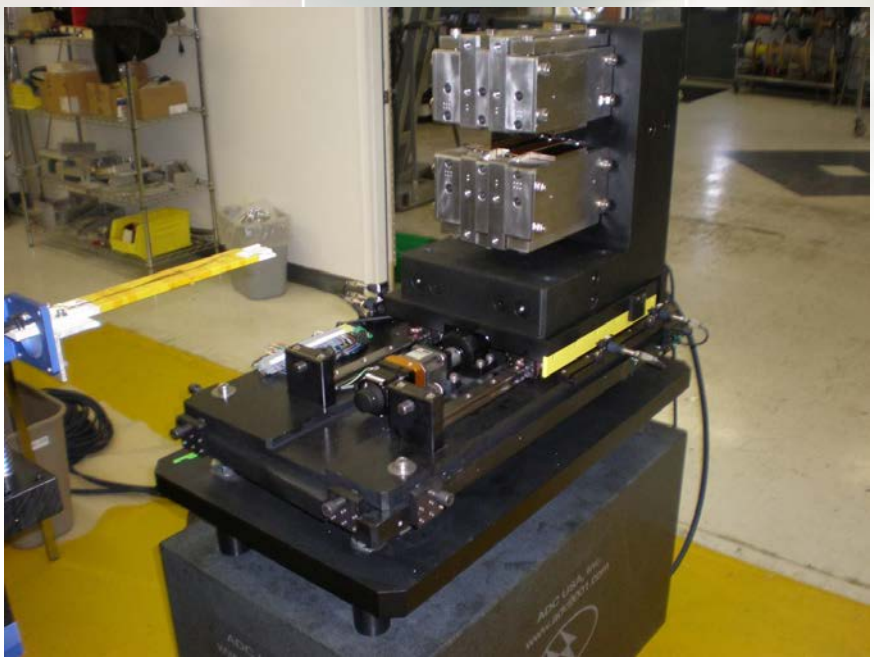


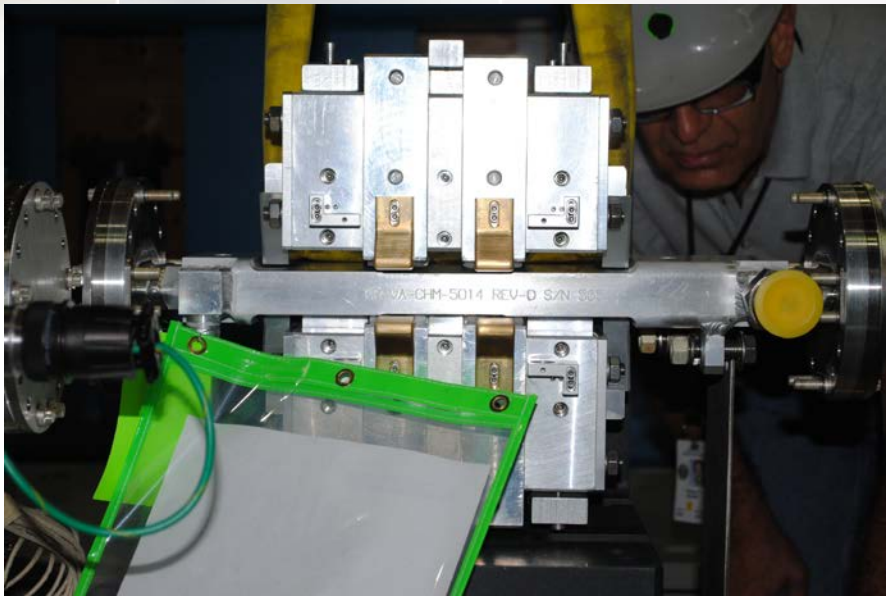


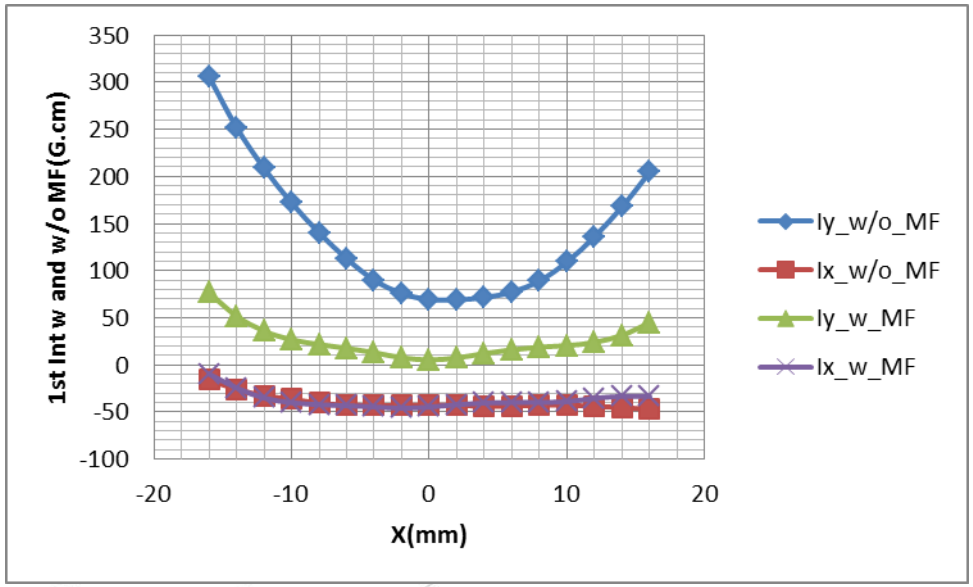
	Open	Closed w/o CS	Closed w/ CS
Measured ν_x	0.20458	0.19216	0.20307
Expected ν_x	N/A	0.19156	0.20422
Measured ν_y	0.25397	0.25804	0.25610
Expected ν_y	N/A	0.25802	0.25567

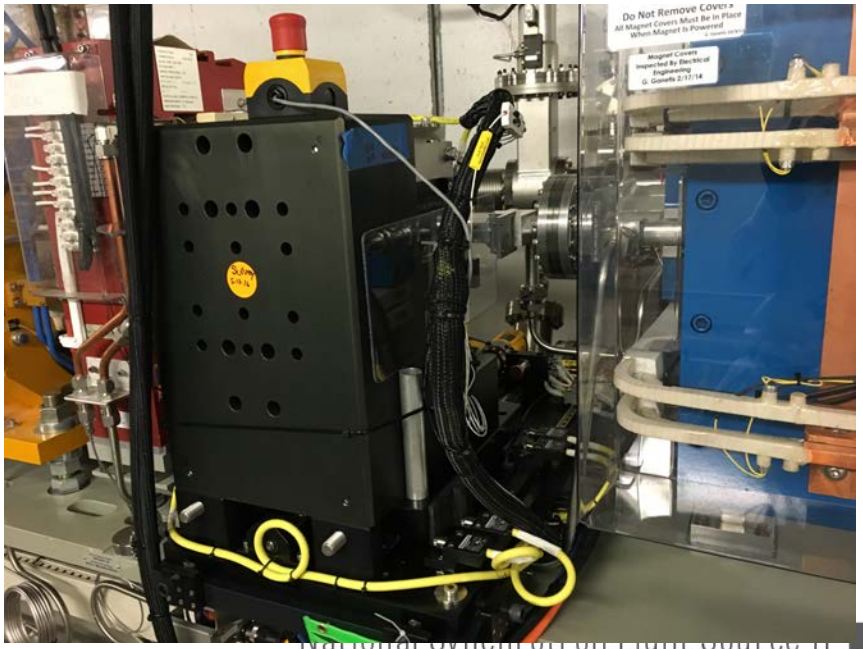
- Three Pole Wigglers (3PWs)

3PW Photos & Magnetic Measurement Results





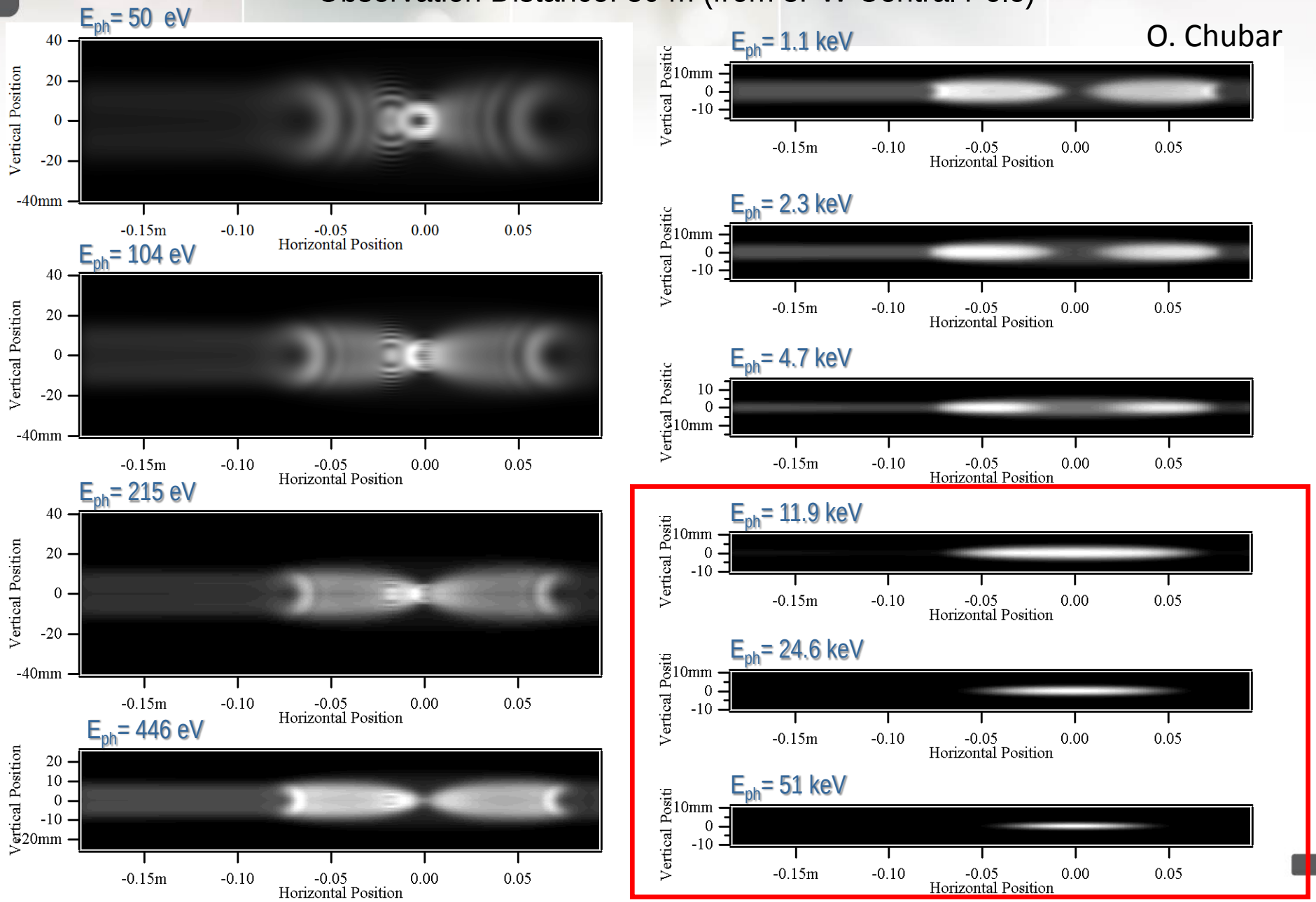




3PW+BM Radiation Intensity Distributions

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

O. Chubar

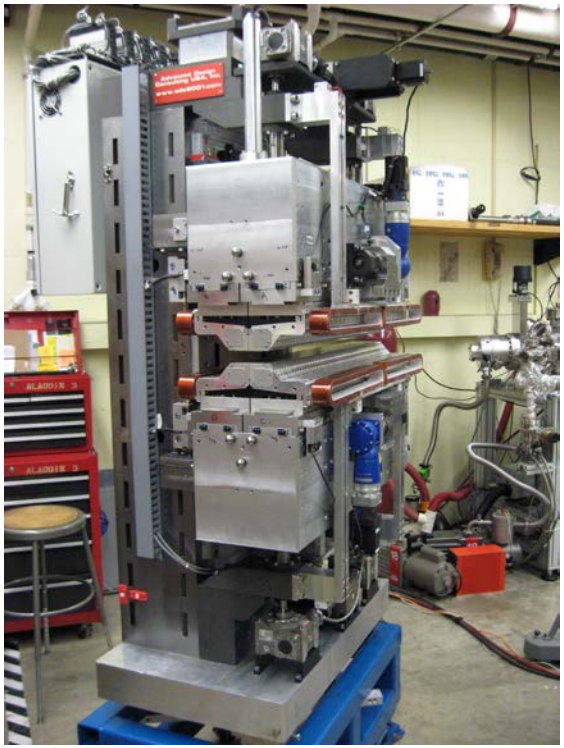


Partner Beamline Insertion Devices (Refurbished)

- Control system upgrade (changing to/adding Ranishaw linear encoder & DeltaTau controller)
- Adding/retuning magic finger magnet configurations.

Refurbished IVU18 from NSLS for NYX

1.0m-EPU60 from SRC for SST2

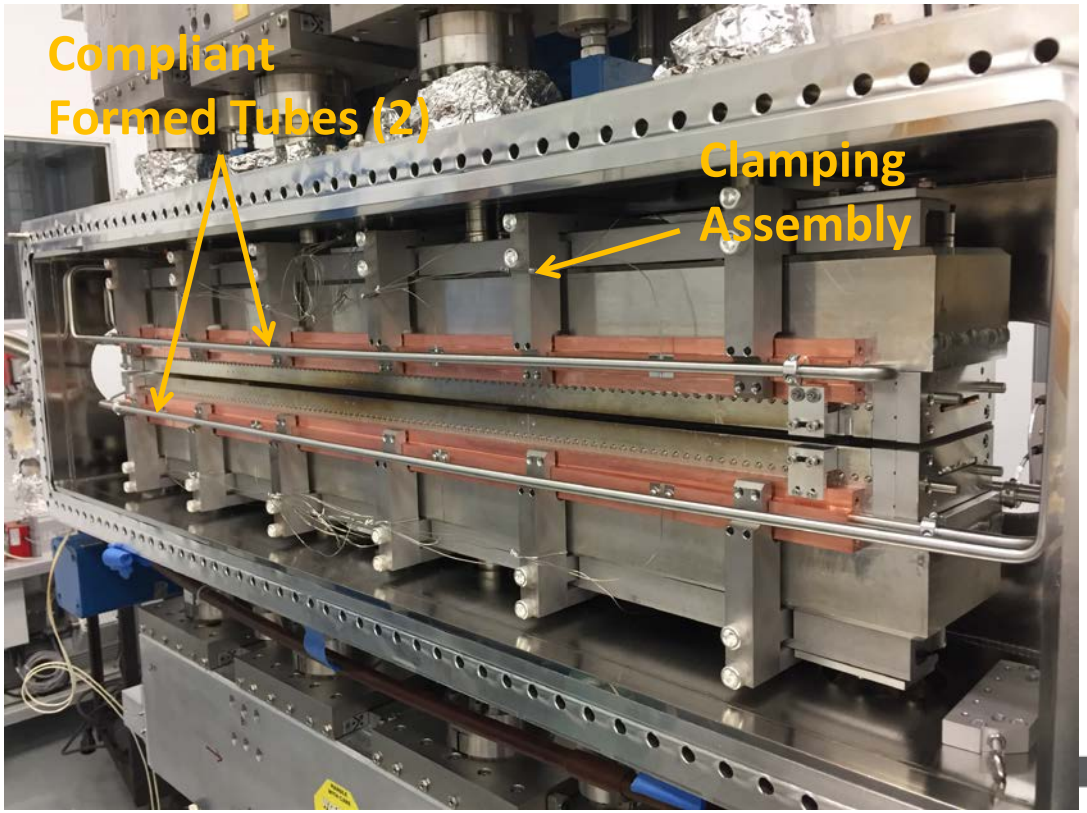


Refurbished ESRF U42 for SST1

Retrofit of Cooling System of Former NSLS CPMU

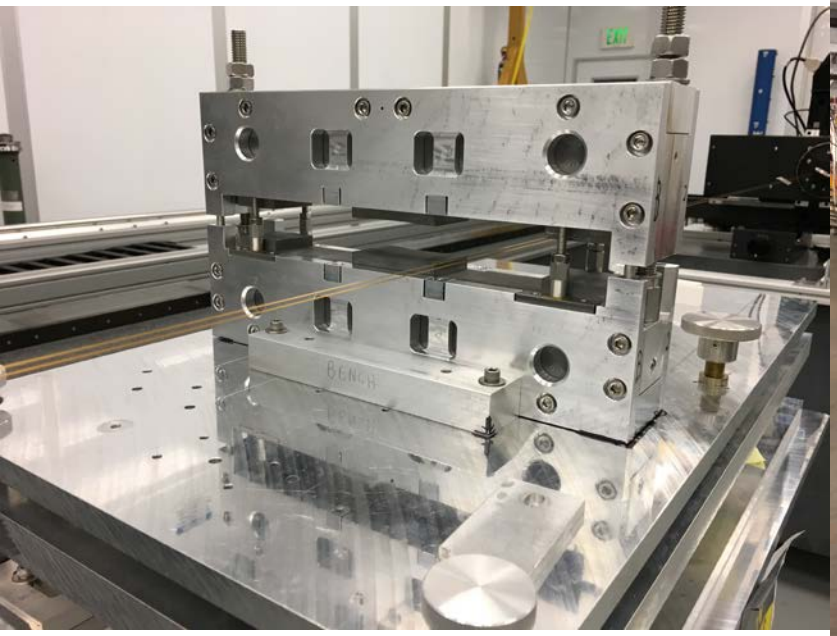
- Original cooling circuits are designed to use cold He gas
- Water cooling was used instead, which has corroded the internal wall
- Water started slowing leaking to the insulated vacuum section

- New water cooling circuits by using two separated compliant formed tubes
- Tubes were stress relieved by baking at high temperature (>1050C°)
- Indium sheet is inserted between the pipes and Cu bars to ensure good thermal conduction



PM Canting Magnets (ESRF Design) in SST Straight

- Thanks to thinner vacuum chamber than other canted straights, PM (SmCo) canting magnets can be utilized for the SST Straight.
- Canting angles are 1mrad, -2mrad, 1mrad (same as EM canting magnets)



- ID Control System Upgrade

Synchronization between ID and Beamline Equipment through optical fiber link (MACRO® Ring)

Purpose: Implement synchronous monochromator and insertion device energy scans (on-the-fly scan) with ***low- level optical fiber network***

SLS Example using EPICS network
(J. Krempasky, et. al. AIP Conference Proceedings 1234, 705 (2010))

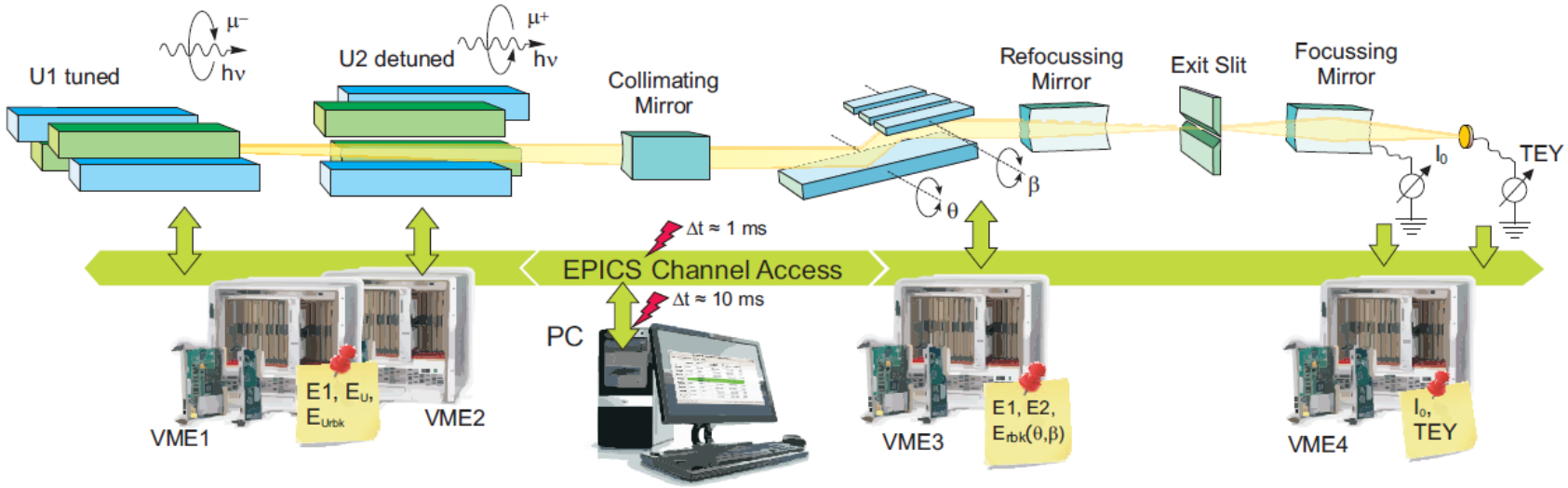
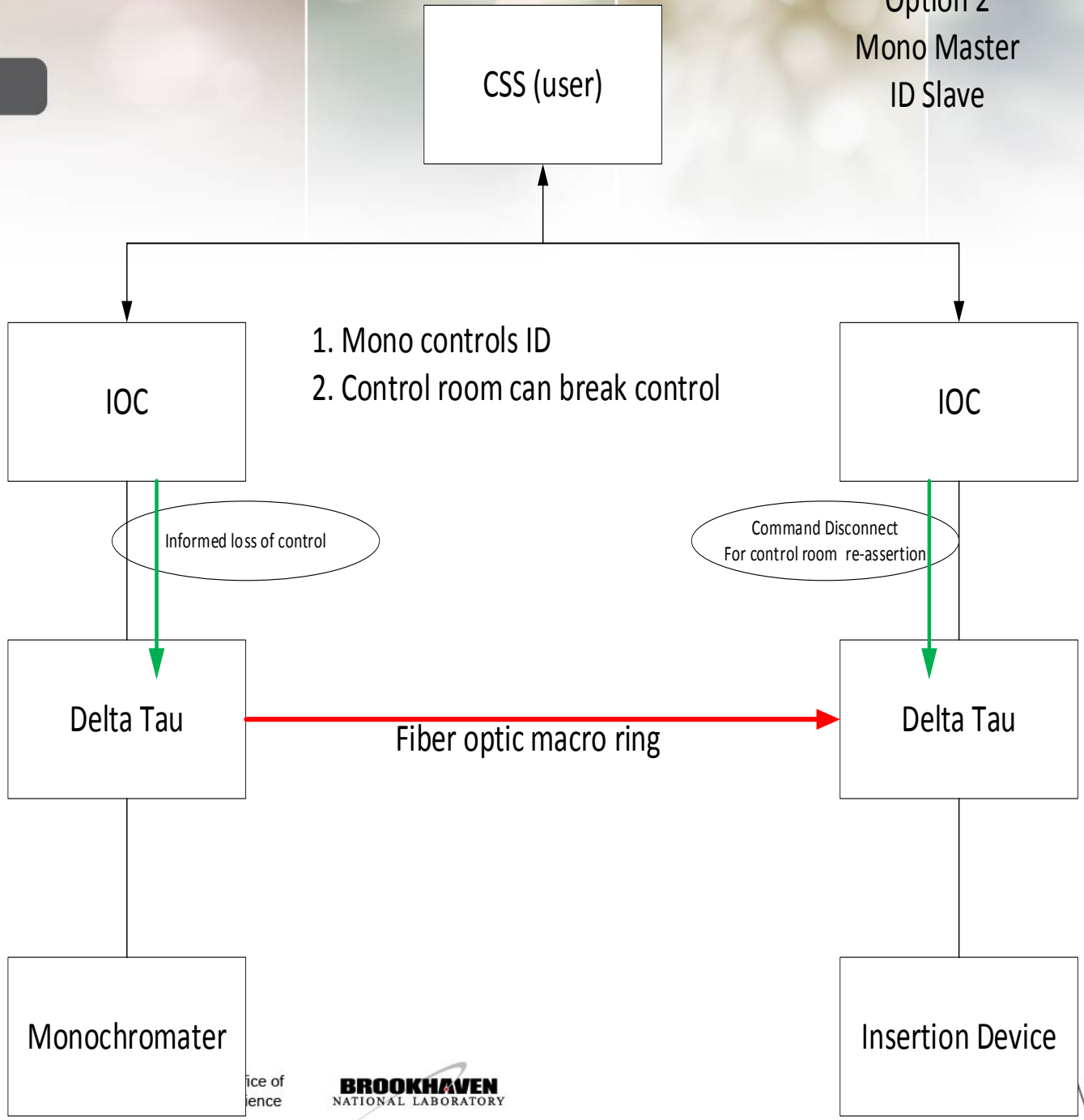
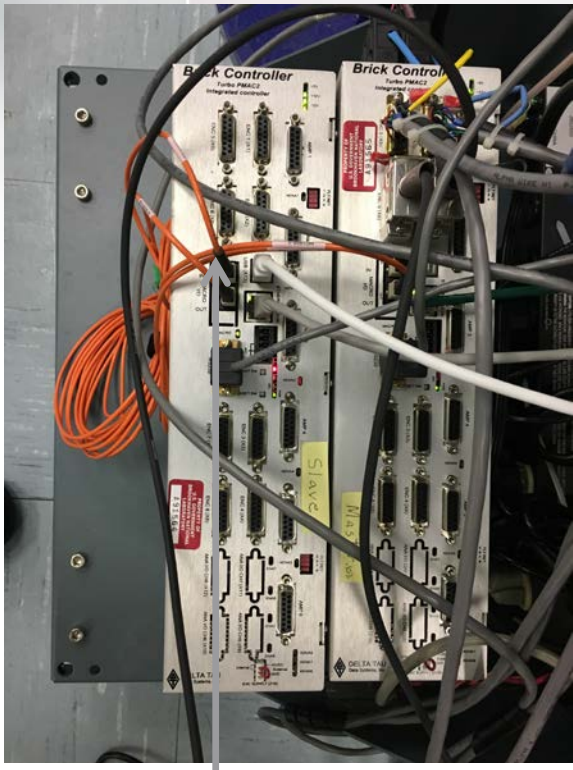


FIGURE 1. Schematic layout of the SIM beamline with underlying computer control equipment. The EPICS control variables are indicated at each of the VME crates. Also indicated are CA latencies in milliseconds (see text).

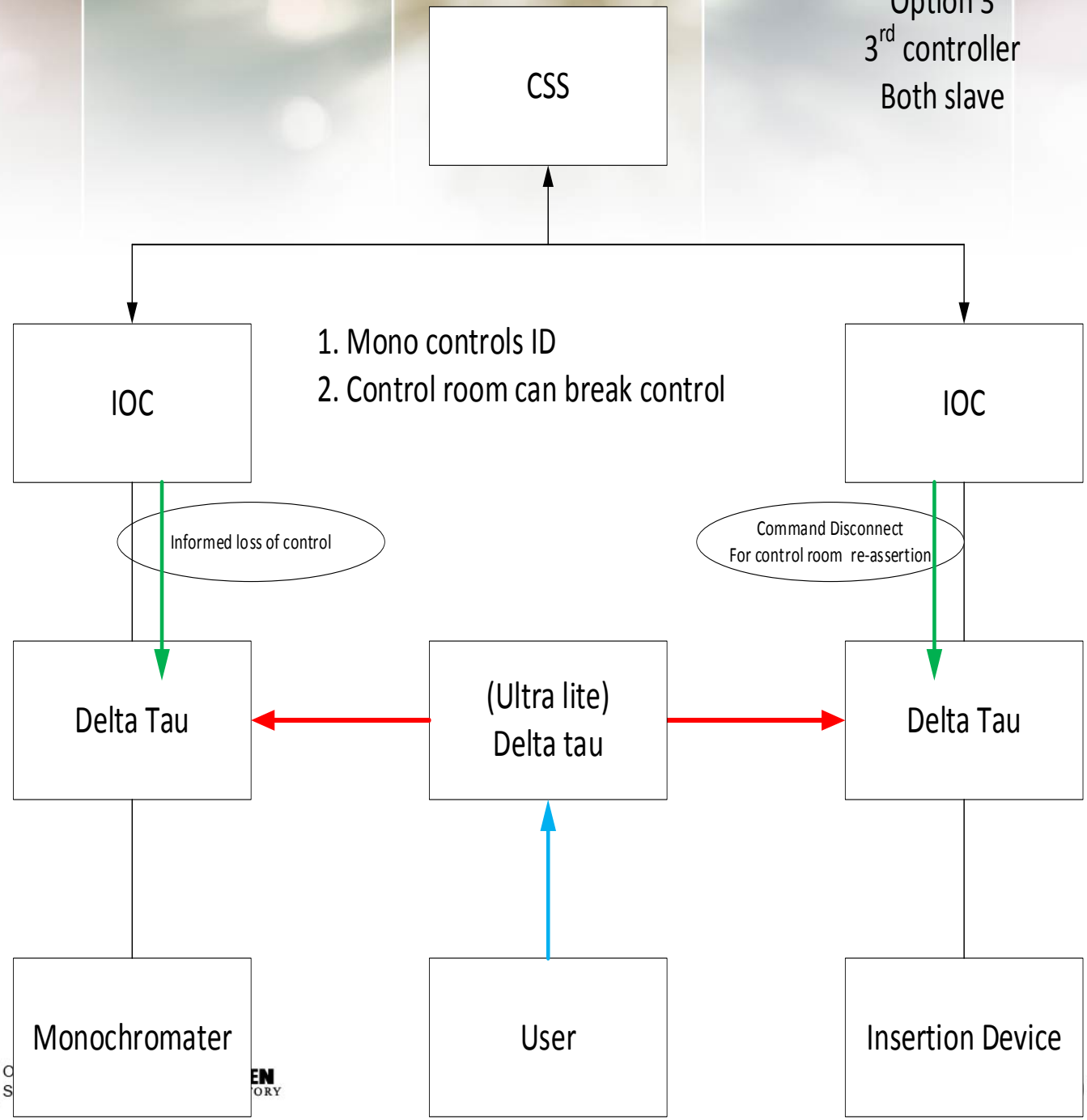
Option 2
Mono Master
ID Slave



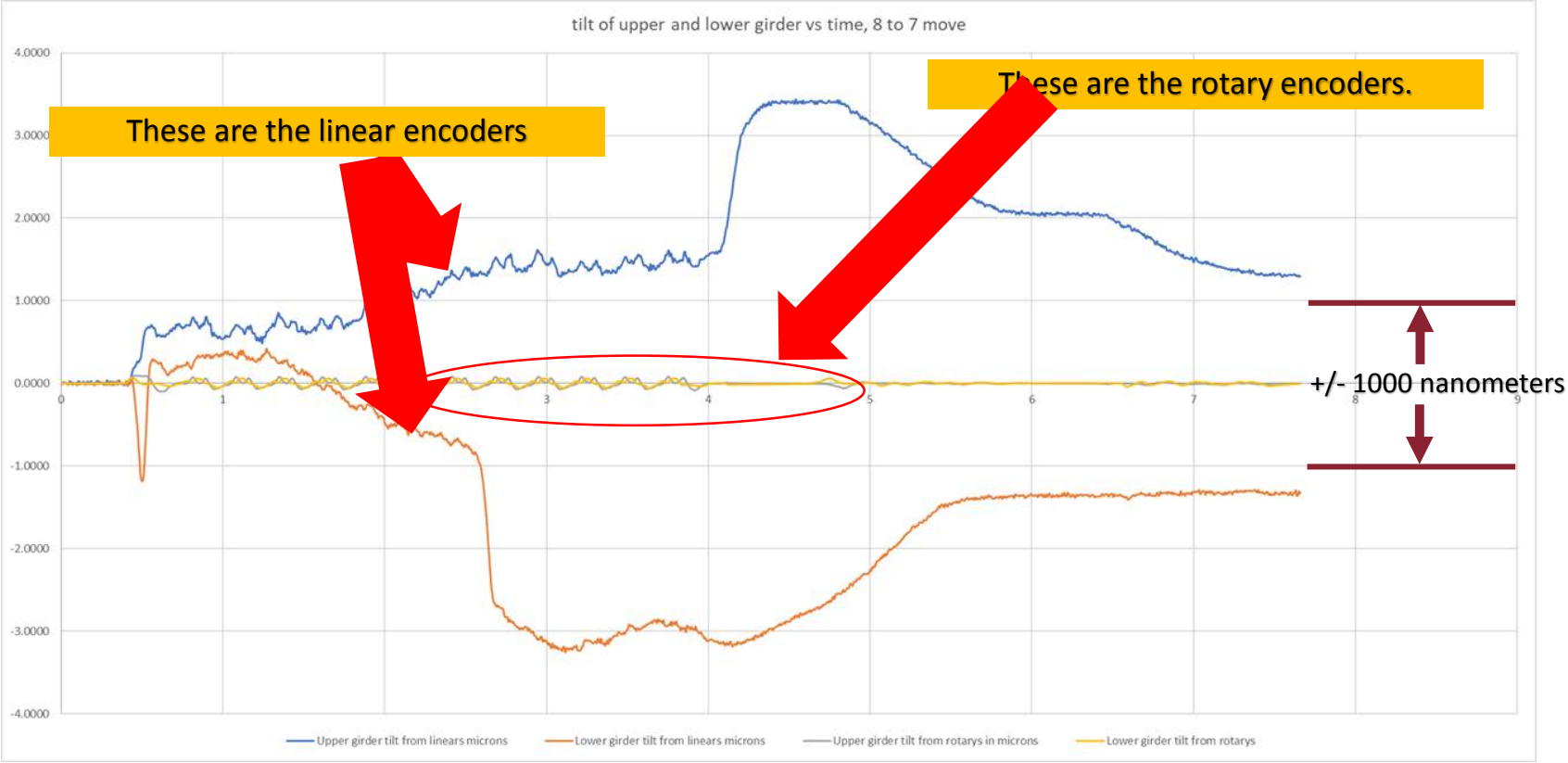


Optical Fiber link

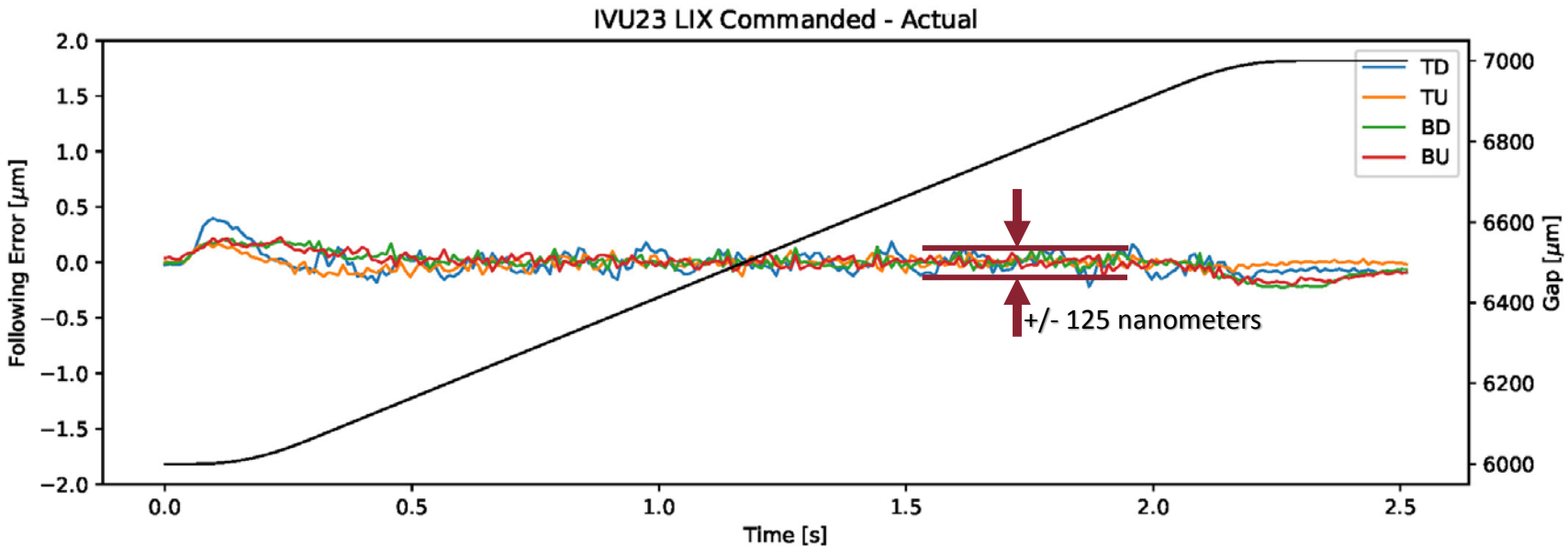
Option 3
3rd controller
Both slave



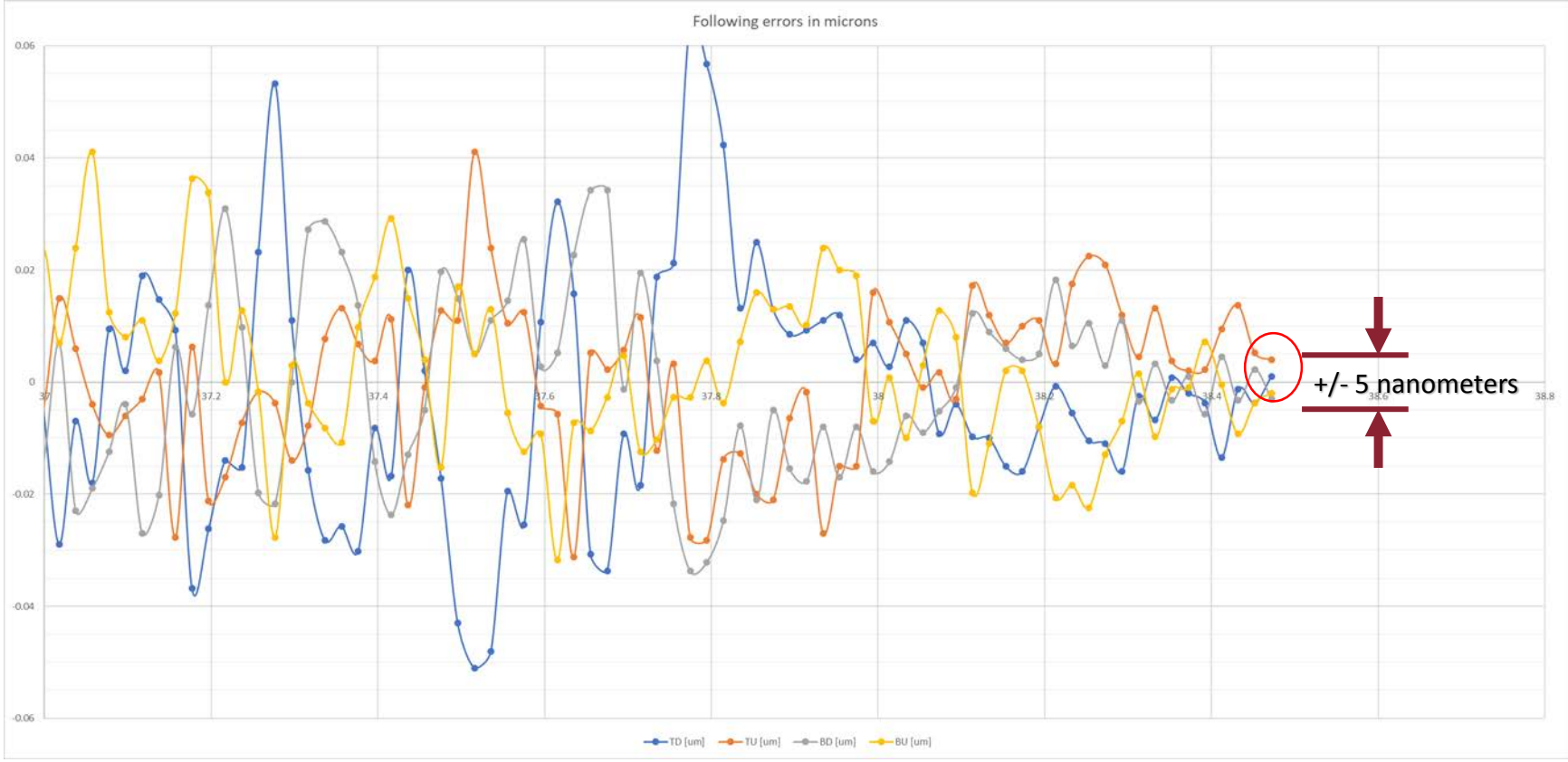
Example of motion of LIX girder: (vendor supplied code)



Example of motion of LIX girder: (New code)

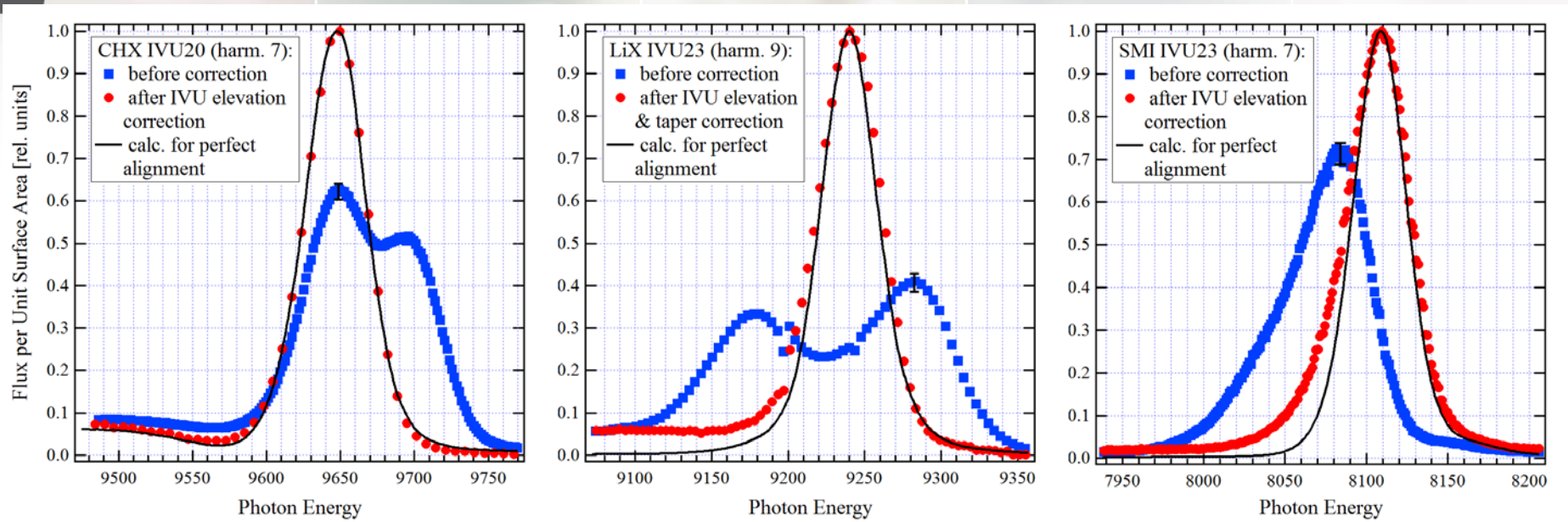


AMX girder (New code)



Spectra Based ID alignment

Courtesy of O. Chubar



- Significant undulator radiation spectra improvement at some IVUs by applying e-beam orbit bumps and undulator gap tapering.
- Adjustment of elevation, undulator taper, and ID-mounted long-coil at SMI (C12 IVU).
- After the alignment, the UR spectra became more sensitive to changes of the electron beam energy spread values → Can be a good diagnostic tool for beam energy spread

Summary

- NSLS-II Insertion Devices for soft and hard X-ray sources perform well as designed despite size restriction and transport limitation.
- Active compensation for APPLE-II devices restores tunes and injection efficiency.
- NSLS-II 3PWs are replacement source for NSLS-BM(1.3T) users. Low energy/imaging users can use NSLS-II BM (0.4T) radiation.
- Small realignment based on its spectra significantly improve the radiation characteristics of IVUs.
- The current NSLS-II lattice is rather sensitive to SQ variation. Reducing operating gap range (max 40mm→ 25mm) and find better working tunes can partially mitigate this isssue.
- Radiation power from DWs (64kW x3) dominates the variation of undulator gap so far to keep constant horizontal emittance.

- Back-up Slides

NSLS-II Insertion Device List (Project IDs)

IVUs are shown in red letter

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	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 12 Insertion Devices (IDs) installed and commissioned as part of NSLS-II Project.

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

IVUs are shown in red letter

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	7.2
SMI	NEXT	IVU23	Hybrid	High-βx	12-ID	2.8	23	0.95	2.05	2.0	6.0	7.2
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	8.3
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	SCW70	EM	Low-β_x	27-ID	1.2	70	4.3	28.1	0	10	55.7

- 11 additional IDs installed and commissioned so far as part of 3 different projects
- 2 SCWs (1.2m, 70mm period, 4.3T) planned in coming years