An Overview of MAX IV Insertion Devices & Magnetic Measurement System

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On behalf of Insertion Devices Team

MAX IV

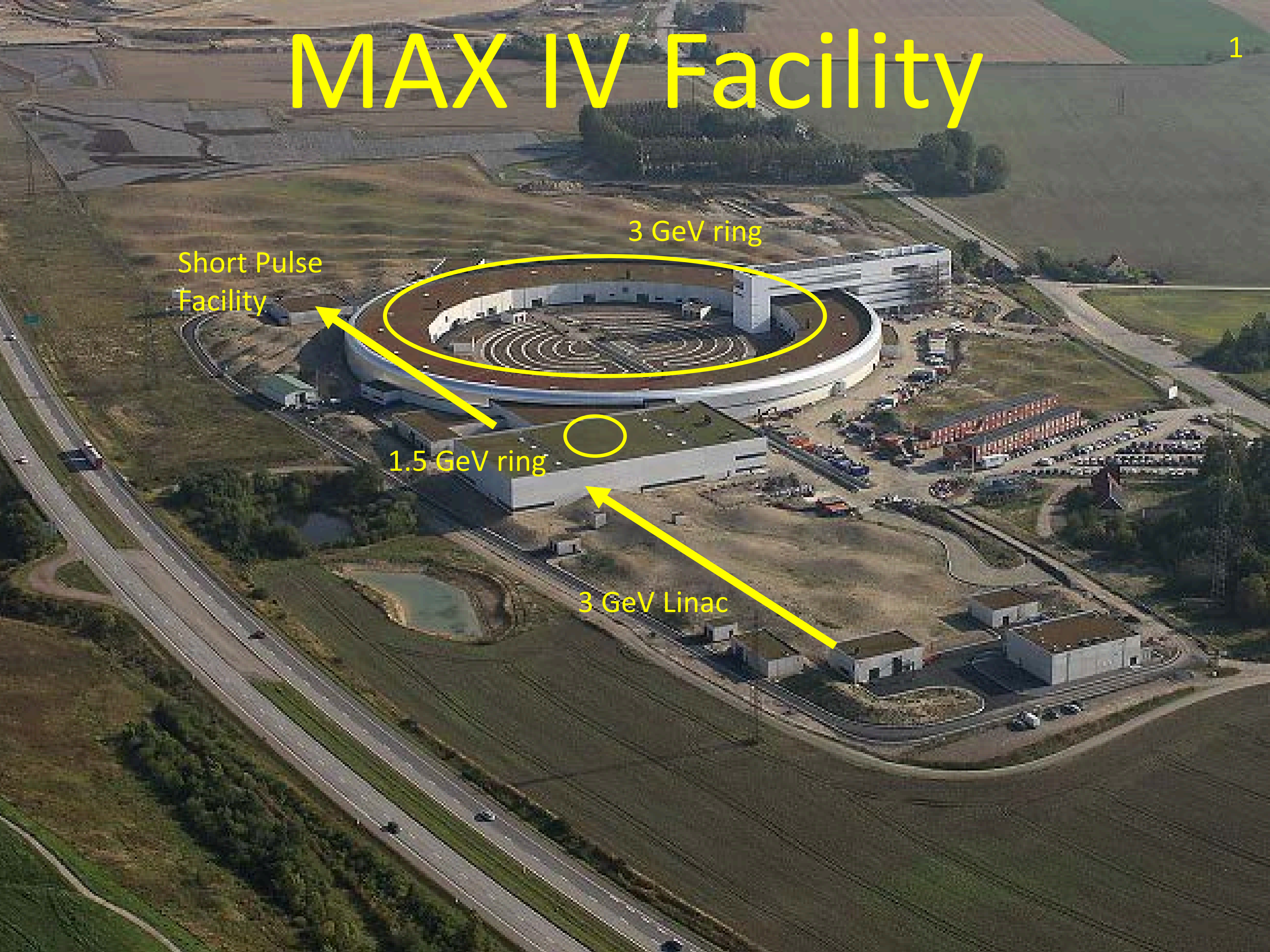
MAX IV IDs & MagLab

Outlook:

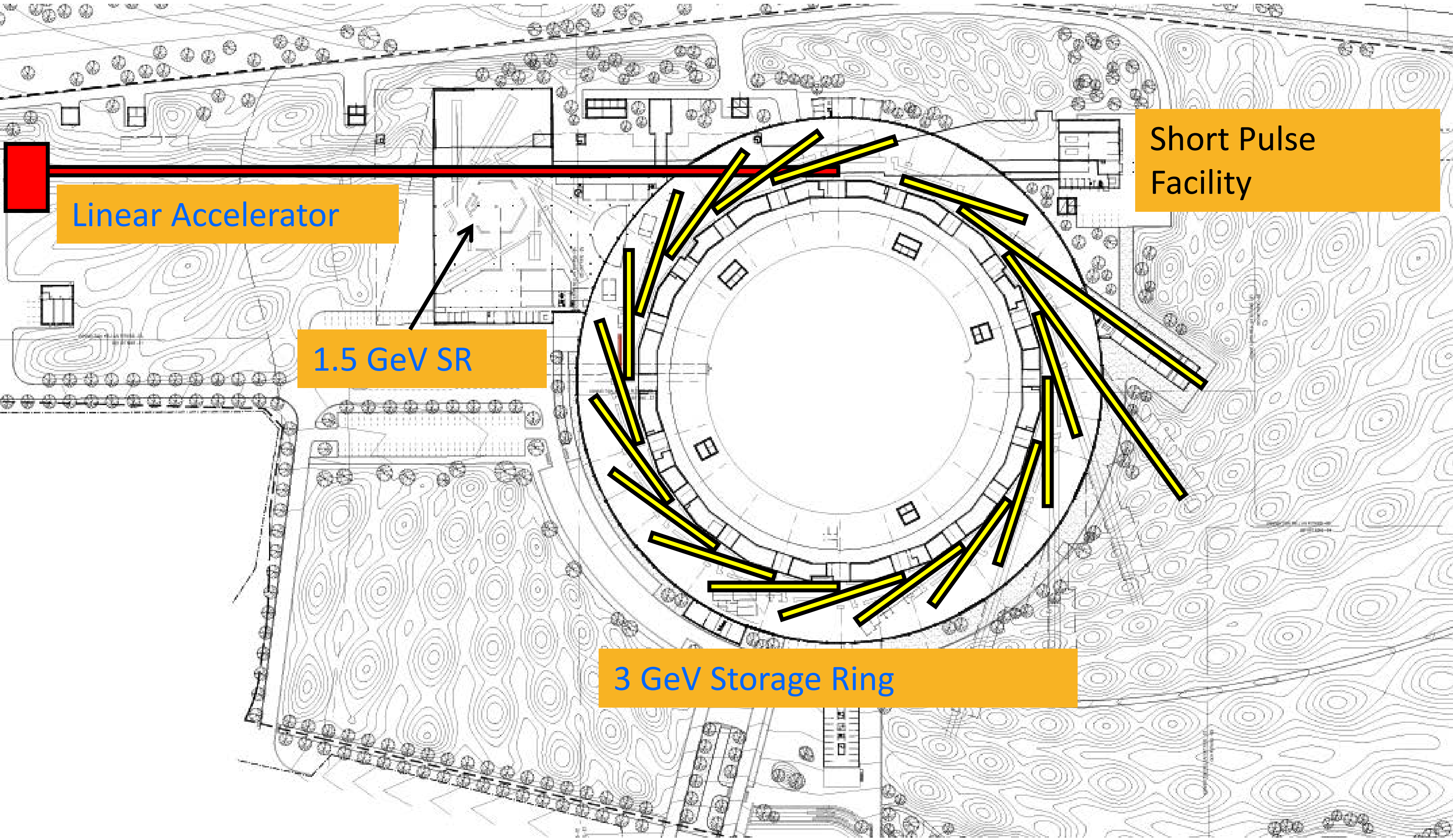
- MAX IV Facility.
- ID Magnet Lab @ MAX IV.
- IDs @ 3 GeV and first commissioning results & Top Up.
- IDs @ 1.5 GeV.
- IDs for future beamlines @ 3 GeV.
- Conceptual studies for SXL FEL Undulators.
- Conclusions

MAX IV Facility

MAX IV Facility



MAX IV Accelerator Complex



List & Status of IDs @ MAX IV

	Beamline ID	ID Type	λ_U[mm]	Length [m]	K_{eff} -value	Magnetic Gap [mm]	ID Status (April 2017)
3 GeV Ring	BioMAX	IVU	18	2	2	4.2	Commissioned
	NanoMAX	IVU	18	2	2	4.2	Commissioned
	Hippie	EPU	53	3.9	3.3	11	Commissioned (only Helical)
	Veritas	EPU	48	3.9	3.3	11	Commissioned (only Helical)
	Balder	IV Wiggler	50	2	9	4.5	Commissioned
	CoSAXS	IVU	19.3	2	2.2	4.2	Installation by Q1 2018
	DanMAX	IVU	16	3	1.66	4	Installation by Q1 2018
	SoftiMAX	Q-EPU	48	3.9	3.3	11	Installation by Q3 2018
1.5 GeV Ring							
	ARPES	Q-EPU	84	2.6	8.65	14	Installation by Q3 2017
	FinEstBeam	EPU	95.2	2.6	10.4	14	Installation by Q3 2017
	SPECIES	EPU	61	2.6	4.85	16	Installation by Q3 2017
	MAXPEEM	EPU	58	2.6	4.95	14	Installation by Q2 2018
	FlexPES	PU	54.4	2.6	4.2	16	Installation by Q2 2018
SPF 3 GeV Linac	FemtoMAX	IVU	15	5x2	2.2	2.2	Installation by Q4 2017

*) Built by collaboration with SOLEIL synchrotron

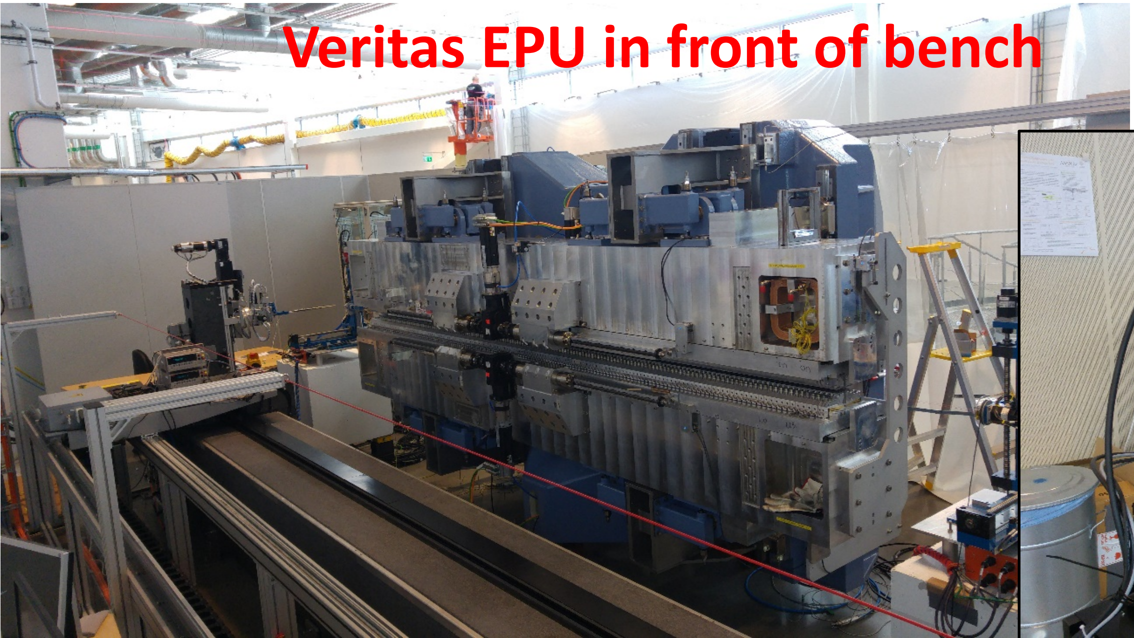
*) Built by industry

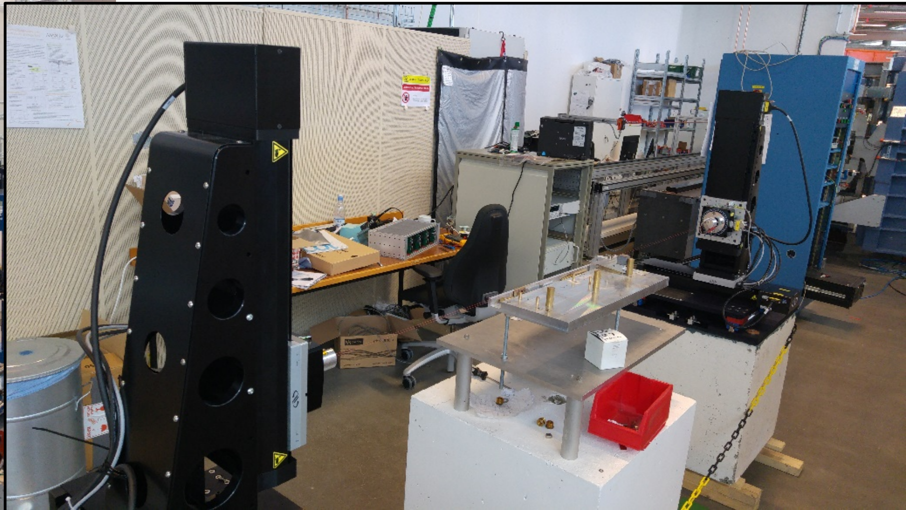
*) To be built in-house (Hippie, Veritas & FinEstBeam are finished)

*) Transfer from MAX-II ring (characterized at MAX IV ID magnet lab)

ID Magnet Lab @ MAX IV

- In-house design, assembly and characterization of undulators is key to meet tight requirements of MAX IV accelerators.
  - Magnet lab infrastructure in 2016.
  - Six EPUs to be built in-house for Soft X-ray BL at the 3 GeV & 1.5 GeV rings.
  - Two undulators from MAX II ring characterization.
- Commissioning of Hall probe bench finished on Feb. 2016.
  - The bench covers 5.5 m magnetic length.
- Commissioning of the flip coil finished Nov. 2016.
  - ID field integrals measurements & magnet block characterization.
- Lab infrastructure for IO and motion tests to minimize tunnel access during installation.
- Building new wire system dedicated for magnet blocks characterization.
  - Develop pulsed wire system (small gap ID)


Veritas EPU in front of bench

Wire system set-up


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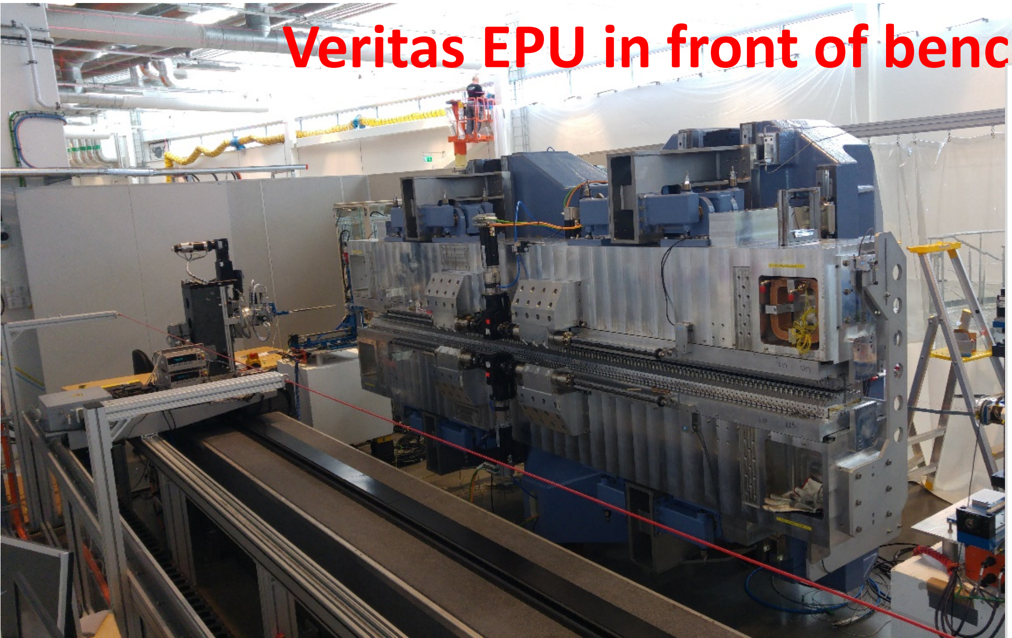

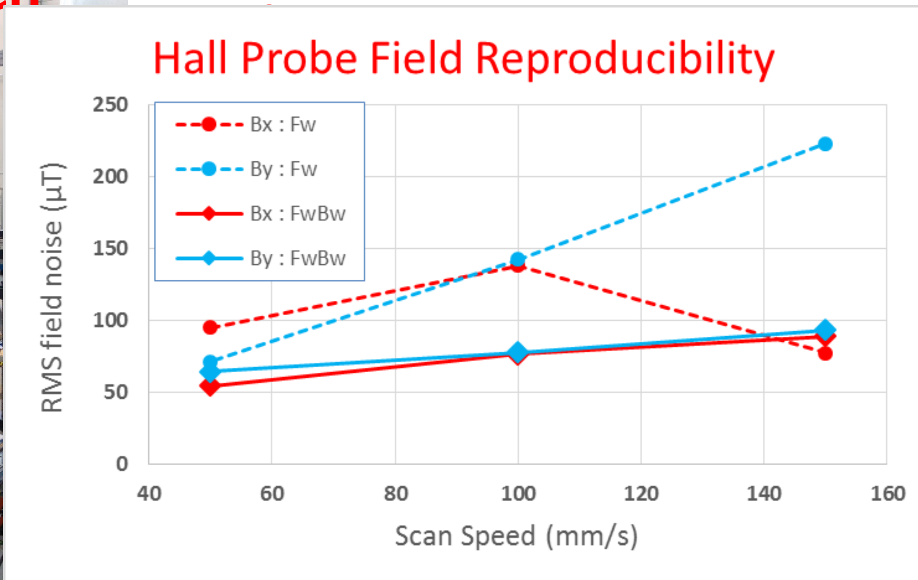

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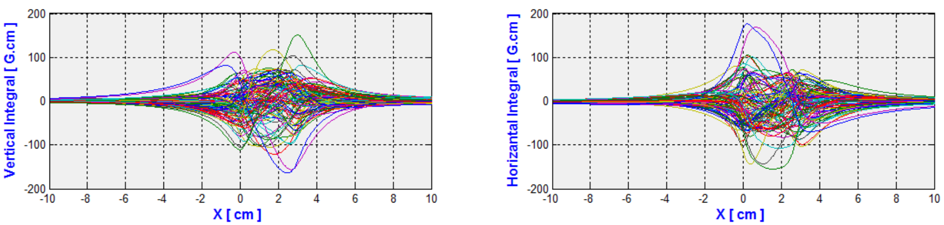
Attribute	Value	Unit	Comment
X, Y max motion speed	200	mm/s	
X, Y motion range	300	mm	
Coil length	4	m	Can be more, but not tested yet.
Coil width (nominal)	5	mm	
Coil number of turns	20		
Wire diameter	64	µm	Insulated CuBe
Field Integral Error, Translate mode	Pk-Pk: 1.5 RMS: 1.0	G.cm	
Field Integral Error, Rotate mode:	Pk-Pk 4.0 RMS 1.2	G.cm	
2nd Field Integral Error, Translate mode	Pk-Pk: 500 RMS: 300	$G.cm^2$	
2nd Field Integral Error, Rotate mode	Pk-Pk: 600 RMS: 300	$G.cm^2$	
Measurement time*, Translate mode	1:15	minutes	-50 to 50 mm, step of 0.5mm
Measurement time*, Rotate mode	5:00	minutes	-10:10 mm, step of 1mm

Wire system set-up

EPUs Production & Characterization@ MAX IV

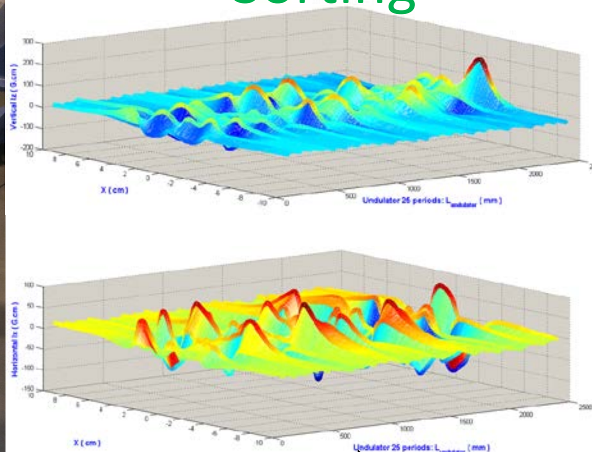
- EPUs built in MAX IV based on the concept of cast iron frame and flexible joints developed at BESSY[1] with modifications (girder with higher force, junction points, gap movement, etc.)
- The use of glued magnets blocks developed at MAX IV[2] and wedges[3] for magnet-holder XY shimming.

Individual Magnet Pairs Measurements



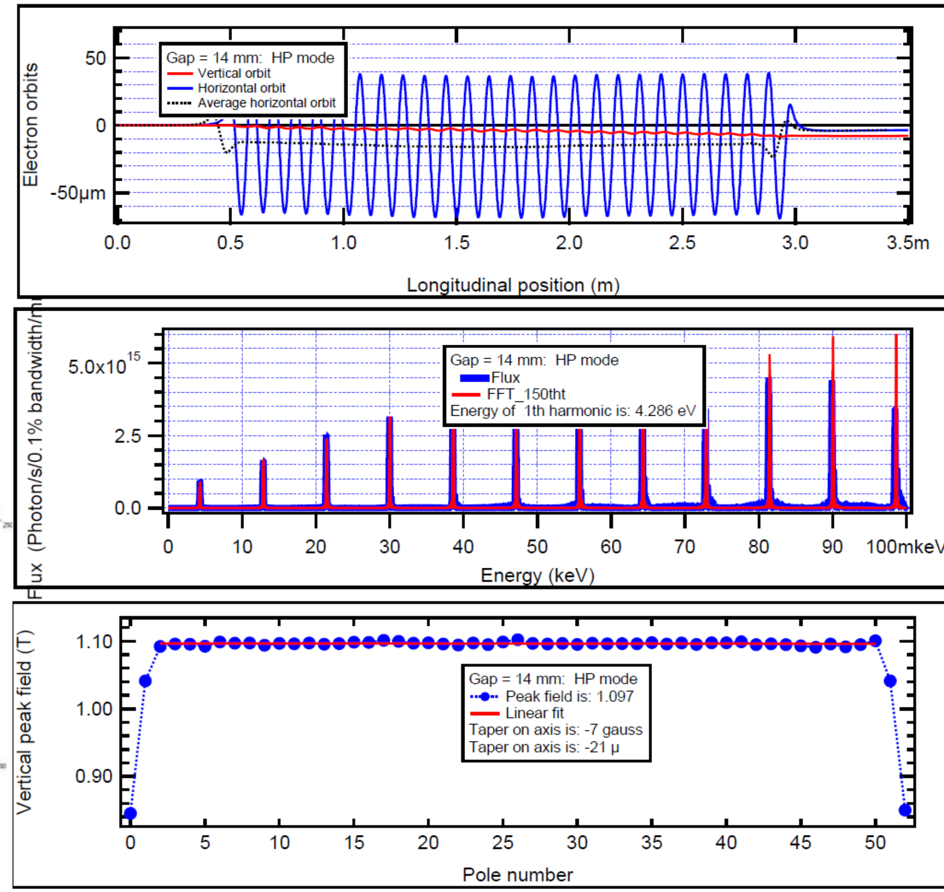
Assembly using extra long stone

Sorting



Shimming & Characterization

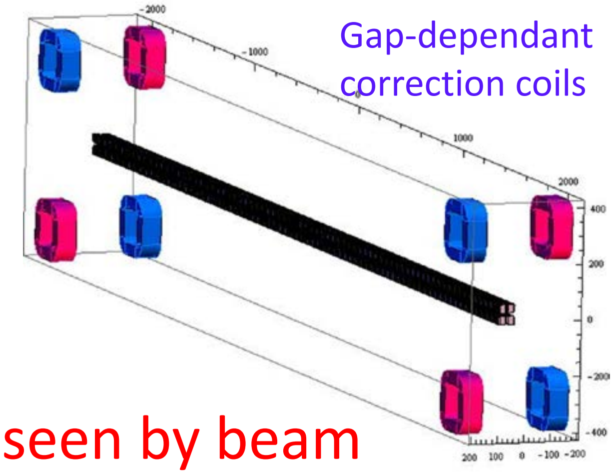
EPU95 Undulator scan on May 19th , 2017



1) J. Bahrdt, et.al. Proceedings of EPAC08, Genoa, Italy
2) E. Wallen, et.al. Proceedings of IPAC14, Dresden, Germany
3) C-H. Chang, et.al Proceedings of IPAC11, San Sebastian, Spain.

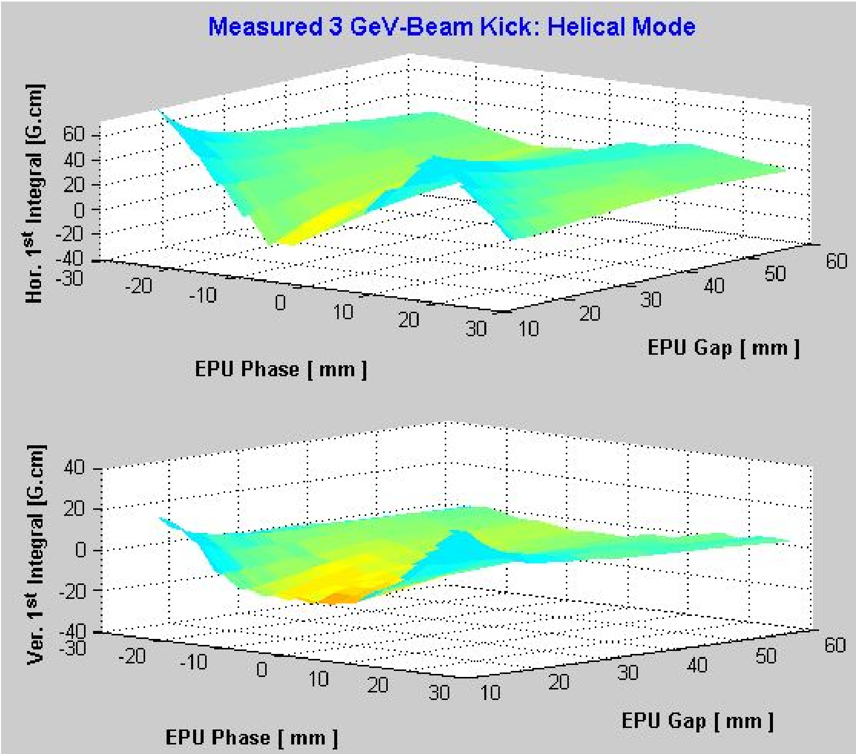
HIPPIE EPU53 & EPU48 Commissioning

- EPU53 & EPU48, 3.9 m long and K=3.3 (All modes).
- Gap-dependant correction coils characterized at magnet bench. Orbit correction has been established for helical mode so far.
- Tune and Skew Q FF schemes (based on LOCO)
- Operation envelope of gap for different phases to achieve 6 kW power limit.

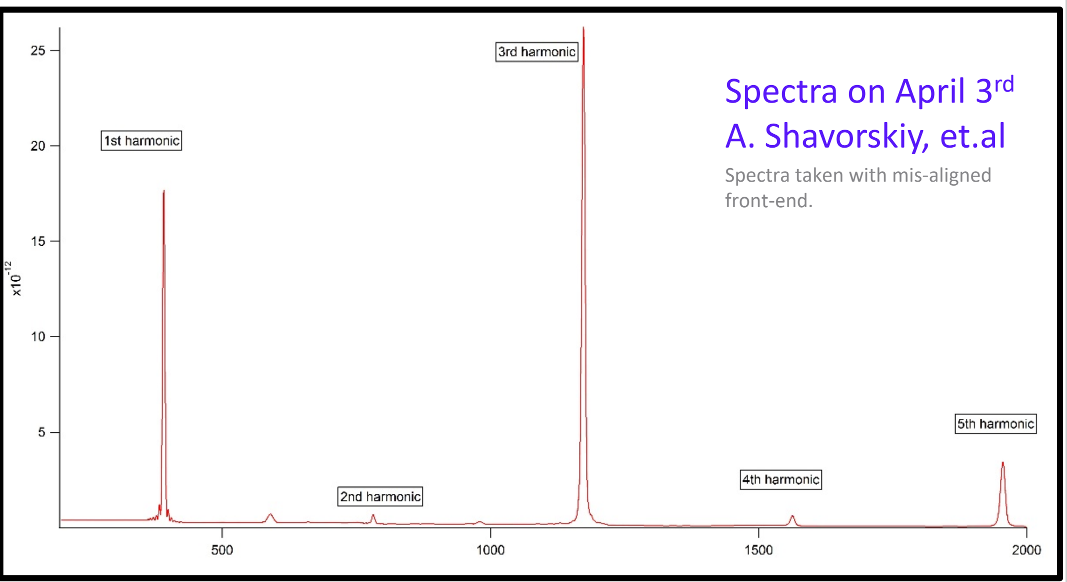


Gap-dependant correction coils

Kick seen by beam



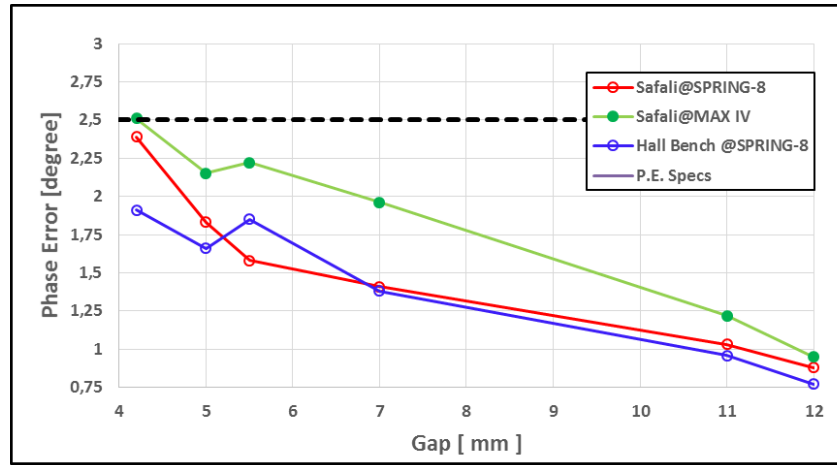
Horizontal Mode Spectrum EPU53

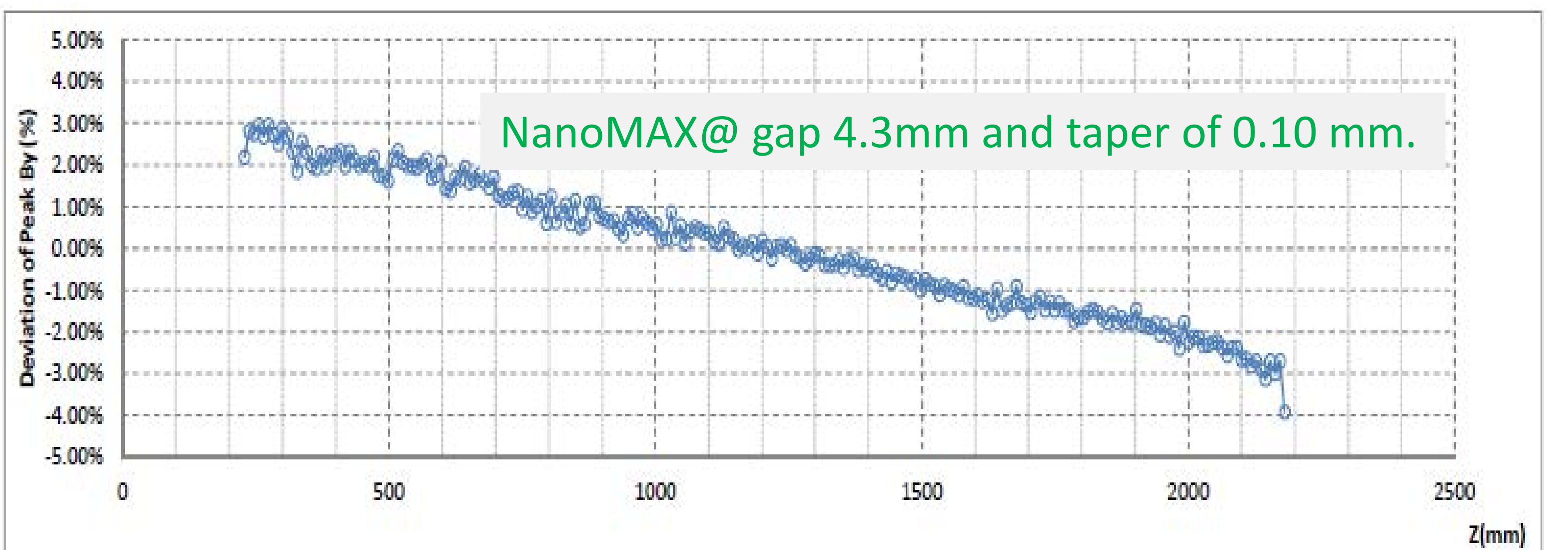


Bio/NanoMAX In-vacuum Undulators

- 2 IVUs for BioMAX & NanoMAX beamlines, λ_u=18mm, Length of 2 m and K_{eff}=1.95 (Achieved K_{eff}=2.19 for BioMAX and K_{eff}=2.10 for NanoMAX at 4.2 mm magnetic gap).
- Two correctors per plane dedicated for each IVU.
- Measured phase error within 2.5 degrees for all operation gaps.
- Each IVU gap is driven by 4 motors to give a tapered gap option. Change of peak field by 5%/m is required.
- New hot-water (110 C) cooling system will be delivered June 2017 to allow baking the undulator in 60 hours instead of 2 weeks.

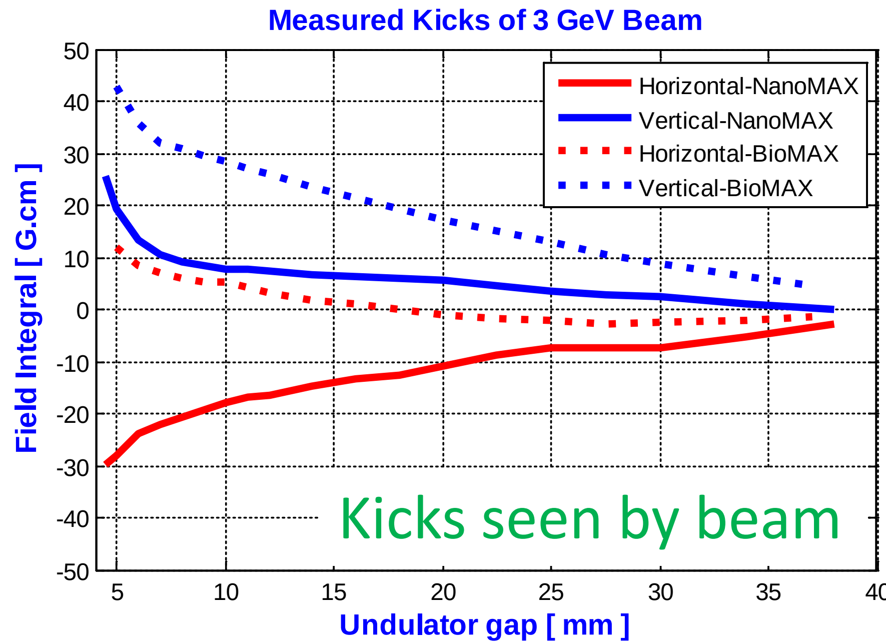
BioMAX: Measured phase error

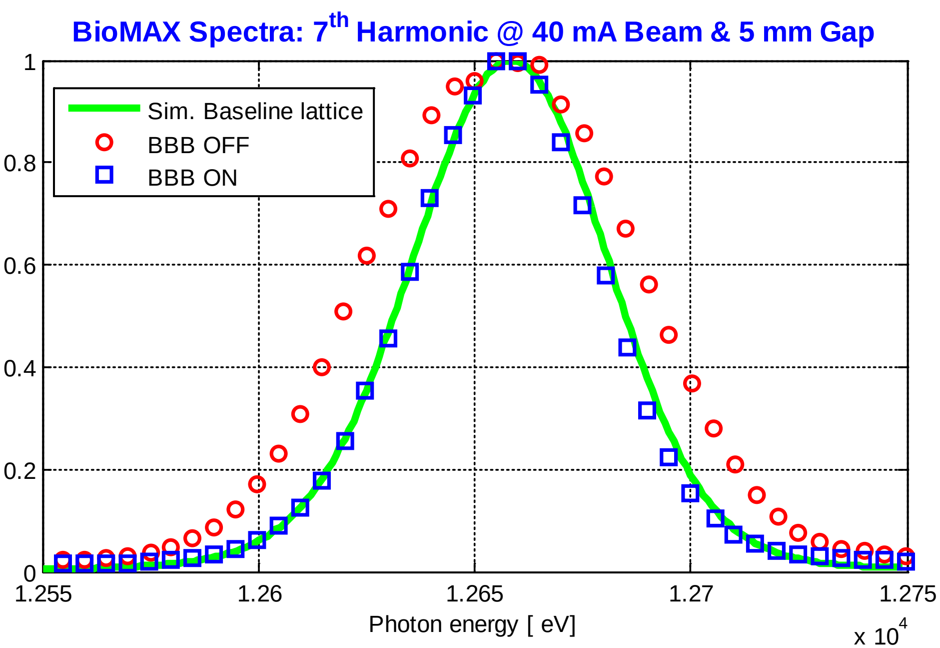


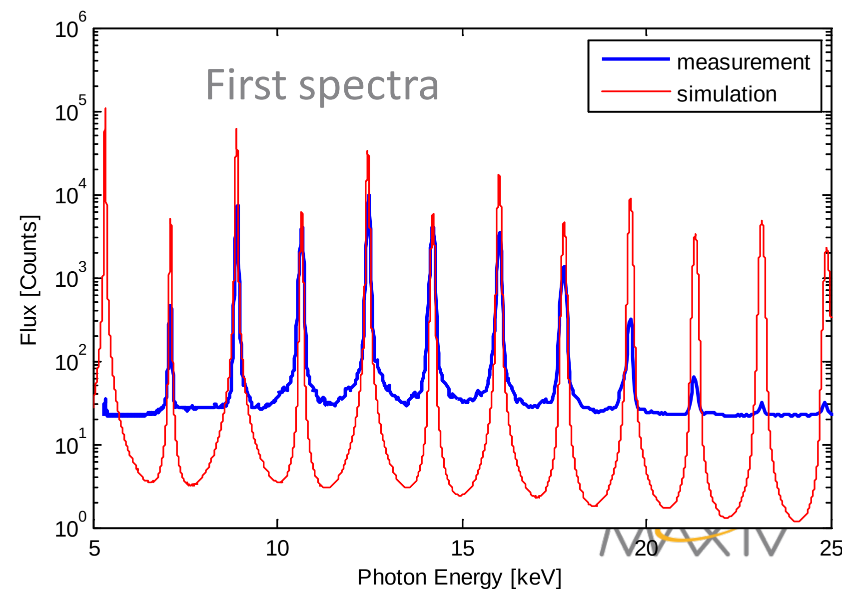


Bio/NanoMAX In-vacuum Undulators

- ❑ Two correctors per plane dedicated for each IVU (±500 G.cm per corrector). Orbit correction has been established for all gaps with max. tune shift <$3x10^{-3}$.
- ❑ Future work to establish correction scheme for tapered IVU.



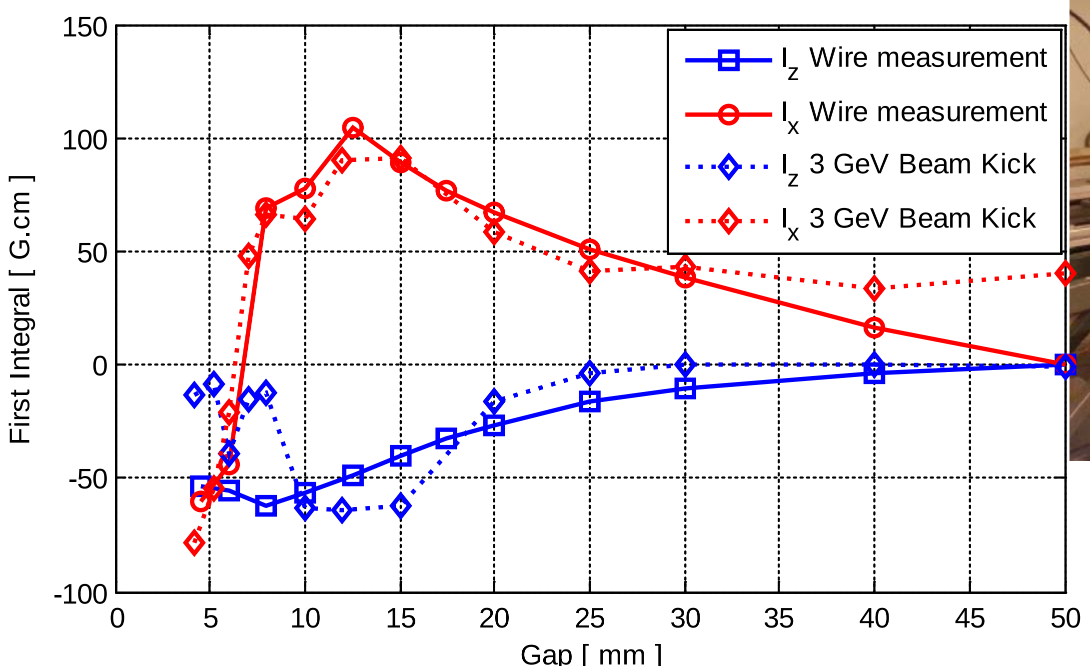




(*) T. Ursby, D. Olsson

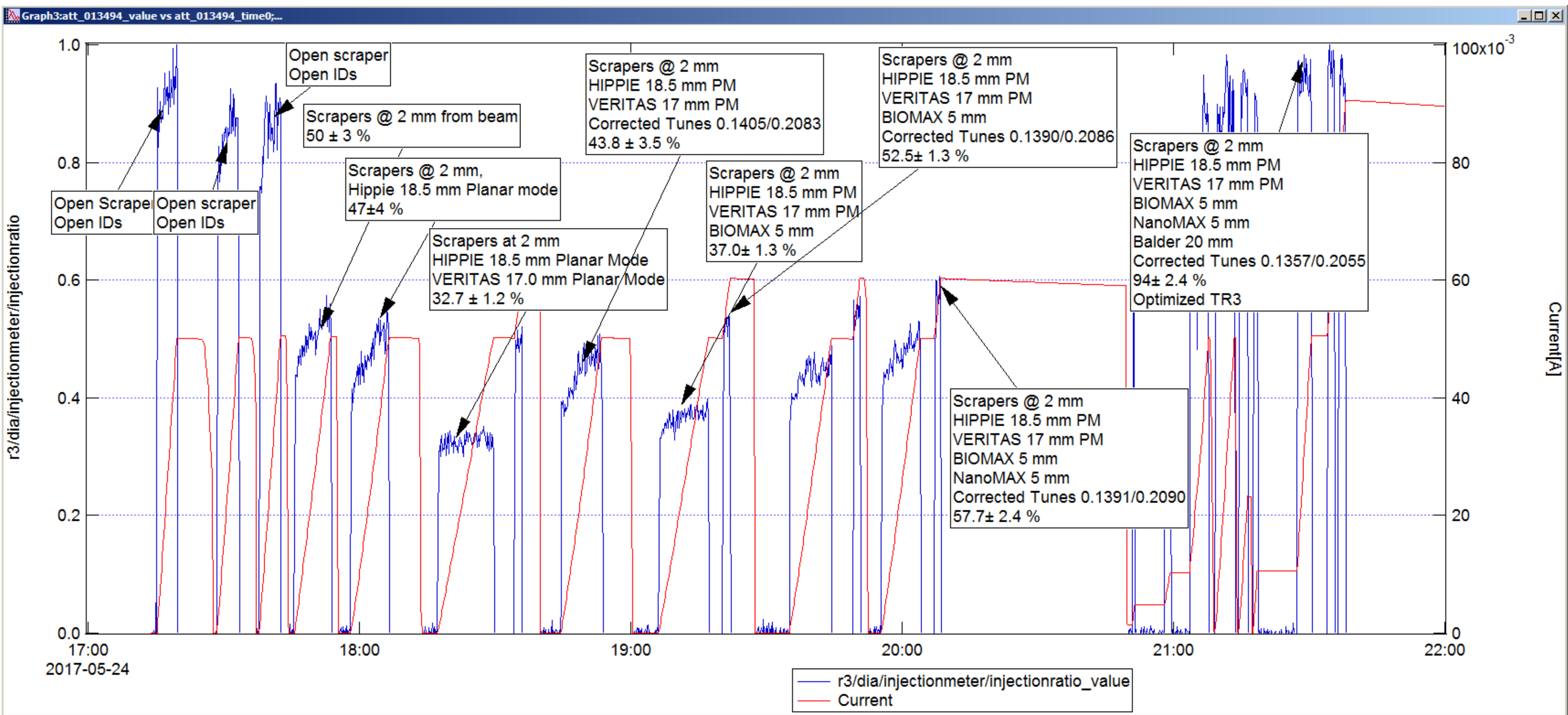
BALDER In-vacuum Wiggler

- BALDER IVW built by SOLEIL , λ_u=50 mm, Length of 2 m and K_{eff}=9.
- The RF transition limits the max. gap from 70 mm to 50 mm (not fully transparent in R3 and has 830 G peak field).
- Early commissioning started Feb. 2017 and the IVW neutralized to 4.5 mm gap.
- At min gap, max. tune shift Q_v= 7x10^{-3} and beta beat 5%. Feedforward tables were established for the orbit and tune.
- Preliminary measurements of damping effect showed ~4% emittance reduction (Theoretically around 5%).



Top up with IDs Closed Gap

- Vertical scraper closed (2 mm). Injected beam has one passage before scraper.
- Radiation safety permission for injection with open shutter NOT yet in place.
- Interlock and routine operation: Closed gap vs. scraper position AND injection efficiency.



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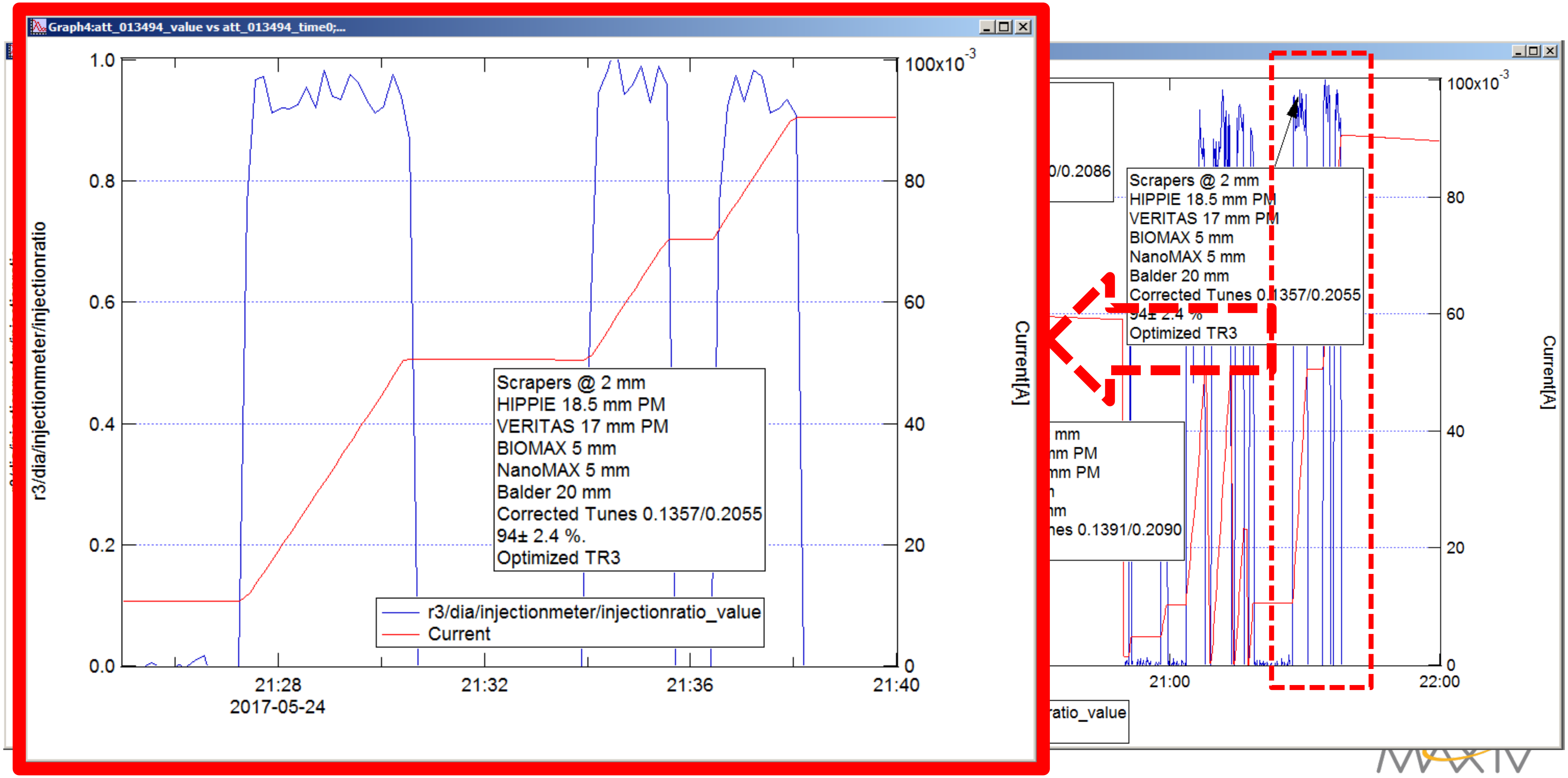
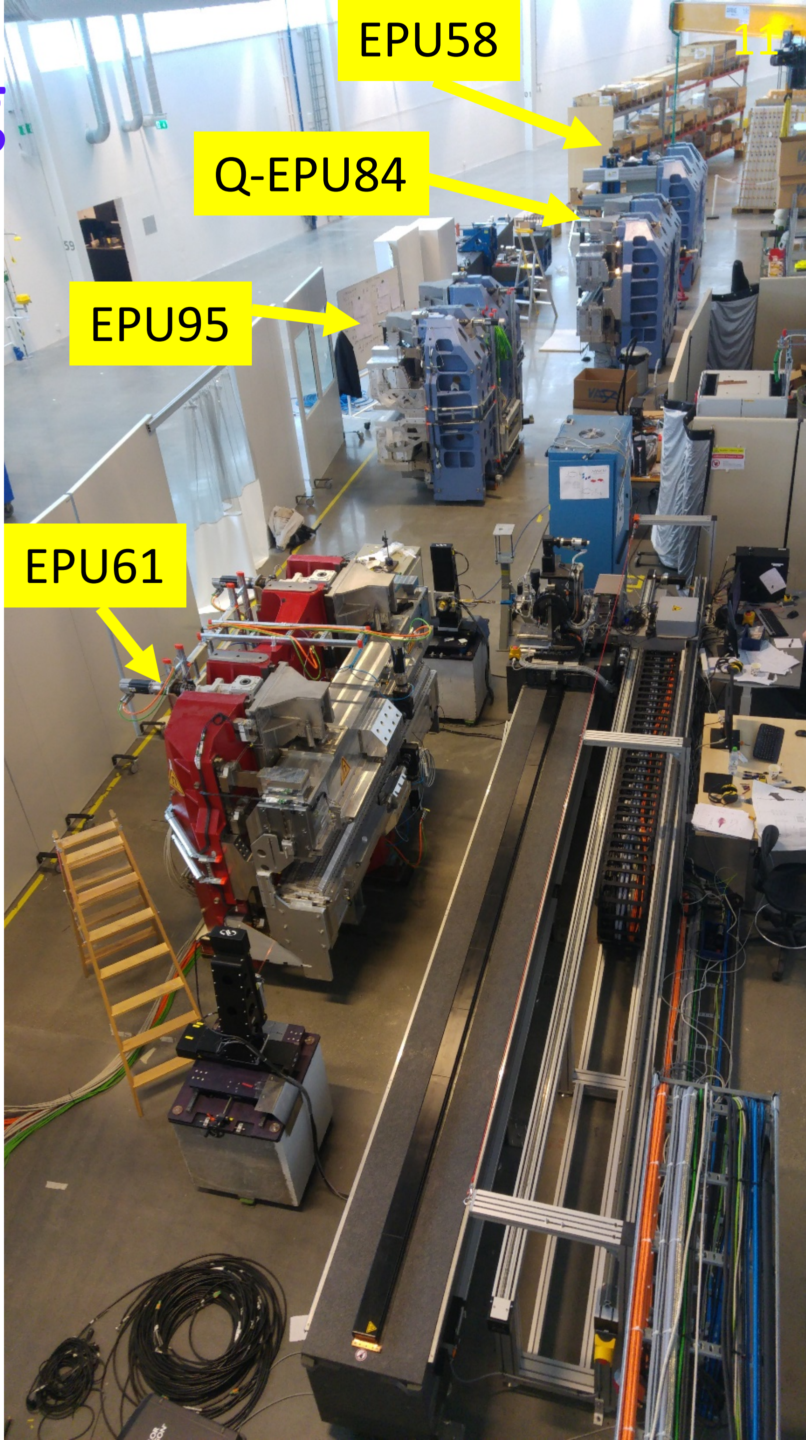


EPUs for the 1.5 GeV Ring

- 3 New EPUs to be built at MAX IV and installed in the 1.5 GeV:
  - FinEstBeam EPU95: 2.6 m long and 14 mm min. gap (4.2 eV).
  - BLOCH EPU84 : Quasi-periodic, 2.6 m long and 14 mm min. gap (8 eV).
  - MaxPEEM EPU58: 2.6 m long and 14 mm min. gap (25 eV).

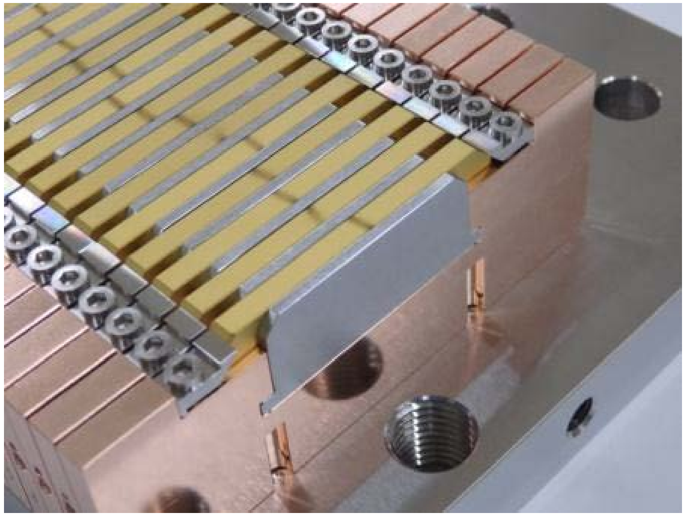
1 EPU and 1 planar undulator transfered from old MAX-Lab.

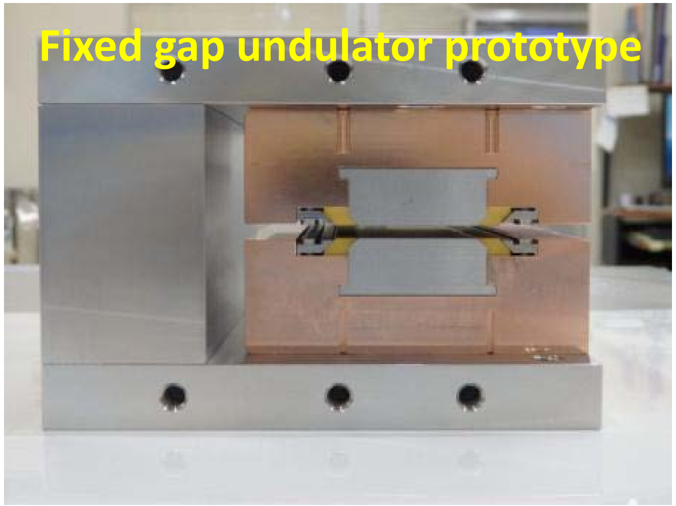
- SPECIES EPU61: Characterized and ready for installation in Q3 2017.
- FlexPES PU54: Refurbishment: change drive system, base system and to be characterized

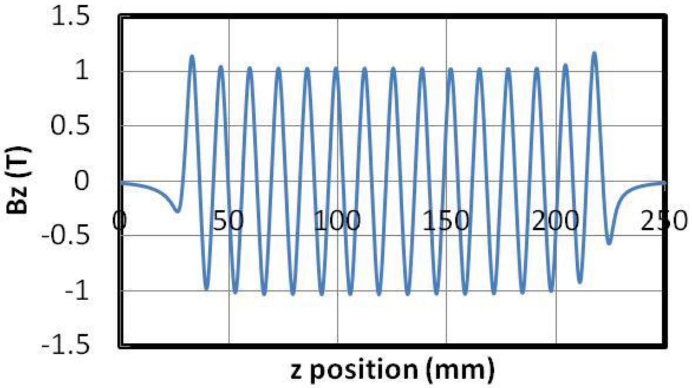


Proposal for Short Period Cryo-cooled Undulator

- Design proposal of CPMU to NMX Engineering-Hitachi in Aug. 2016
  - λ_u=13 mm, K_{eff}=1.58, 2 meter long and min. magnetic gap of 3.6 mm.
  - Baseline lattice allows min. physical gap of 3.3 mm for 2 m-long and centered ID.
  - Demagnetization estimate showed feasibility of assembly at room temperature.
  - Brilliance of 10^{19} @ 50 keV with R3 baseline lattice.







1) λ=13 mm
2) Gap @ 4 mm (Fixed gap)
3) B_{peak} = 1 T @ 300 K.
4) The evaluated B coincides with simulated one.

Magnetic performance @ 77 K by Nov. 2017

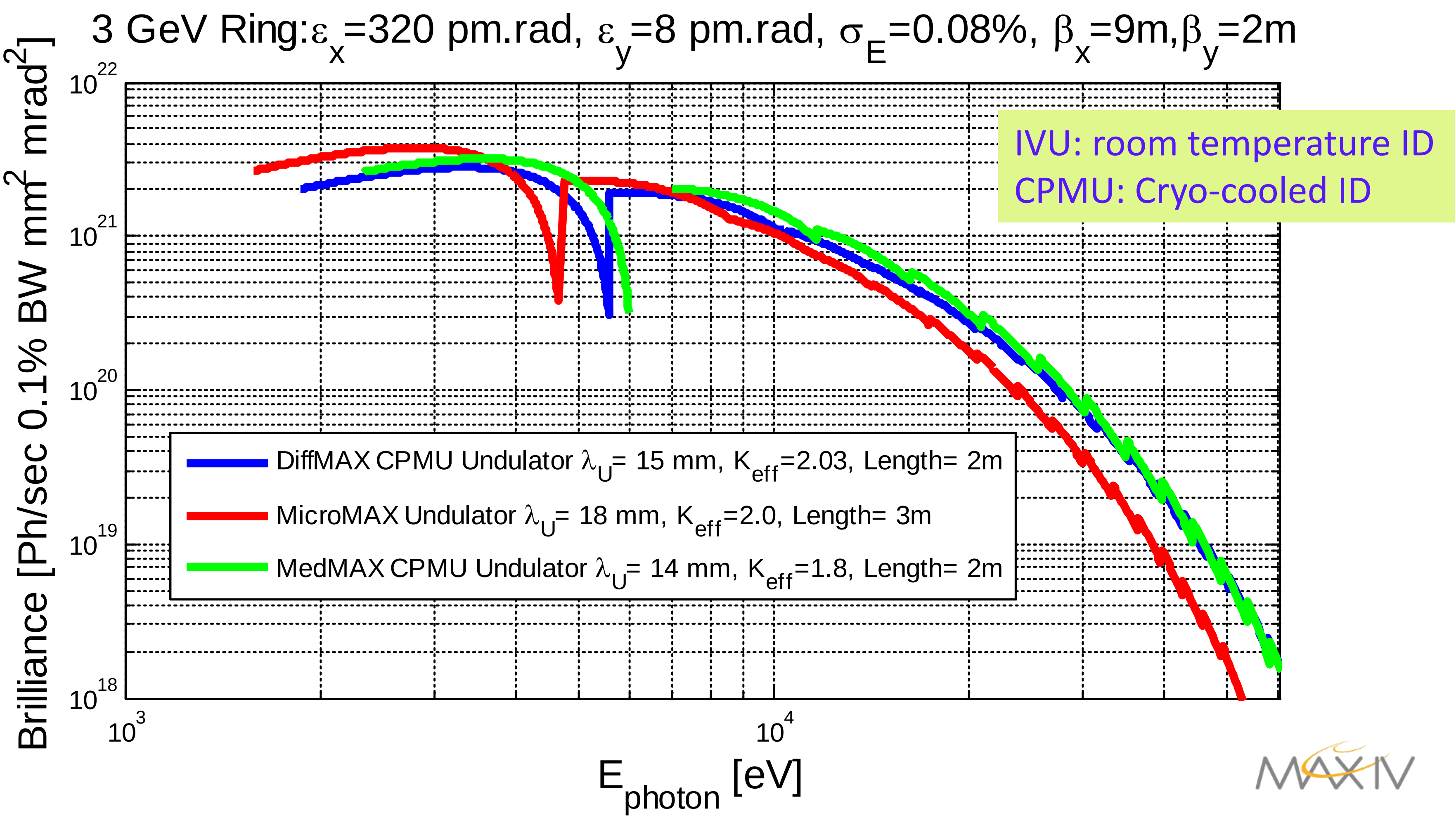
MAX IV

Undulators for Future Beamlines @ R3

(Not funded BLs yet)

Preliminary BL requirements:

- DiffMAX: 3-50 keV (no gap between the 1st and 3rd harmonics)
- MedMAX: 12, 25 & 40 keV (Tapering ΔE/E of 3keV may dictate room temp. device).
- MicroMAX: 5-30 keV



MAX IV

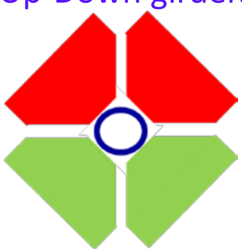
Conceptual Design Studies for SXL Undulators

- ❑ Soft X-ray FEL 1-5 nm wavelengths.
- ❑ Definition of undulator parameter, mechanical design considerations and structural analysis and small gap measurement system.

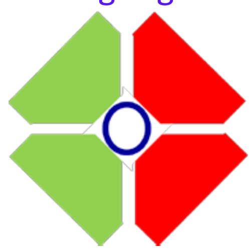
Fixed Gap Undulator Structure

- ❑ Cost effective.
- ❑ Change e-beam energy.
- ❑ Accelerator Lattice.

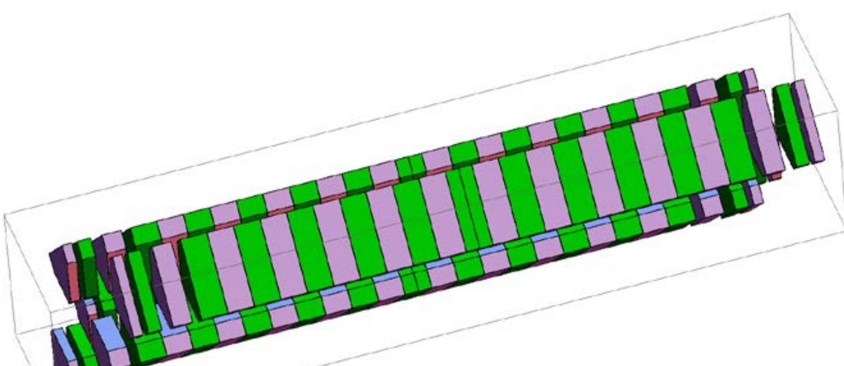
Up-Down girders



Left-Right girders



APPLE X Configuration developed at PSI(*)



(*) M. Calvi, et.al. J. Sunch. Rad. March 2017

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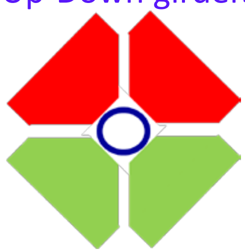

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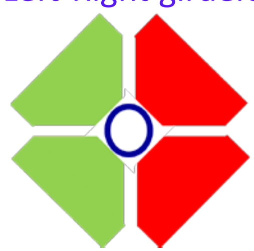
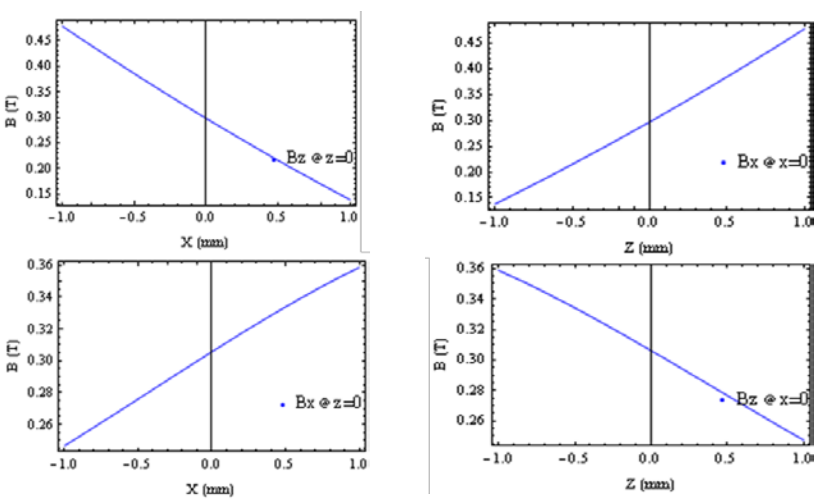


Transverse gradient in K @ 1 keV



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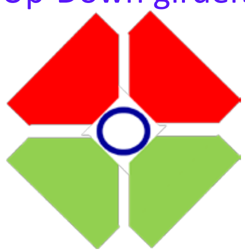

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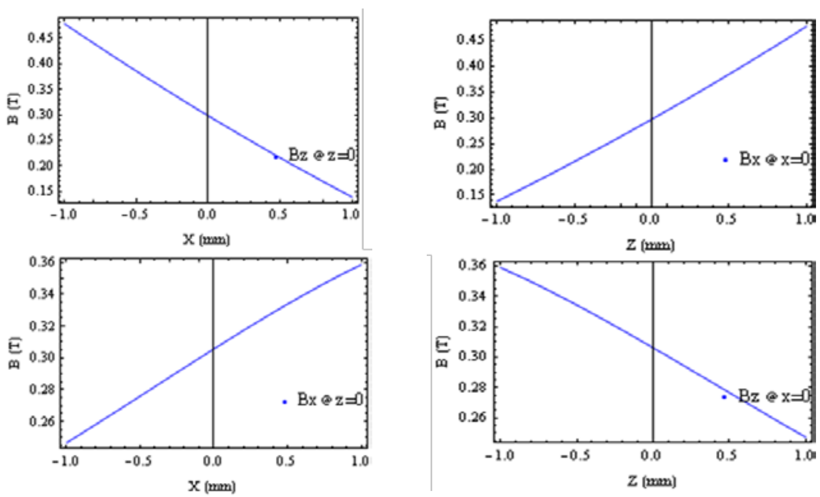


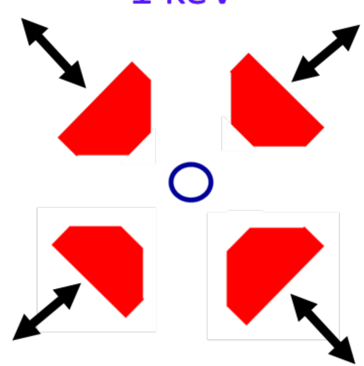
Radial Gap Movement Structure

- ❑ Cost
- ❑ Fixed e-beam energy.
- ❑ Operation modes.

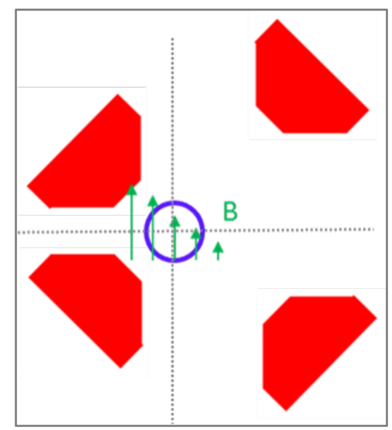
Min. gap:250 eV

Gap ΔR=8 mm

1 keV



Transverse gradient in K as a feature



MAX IV

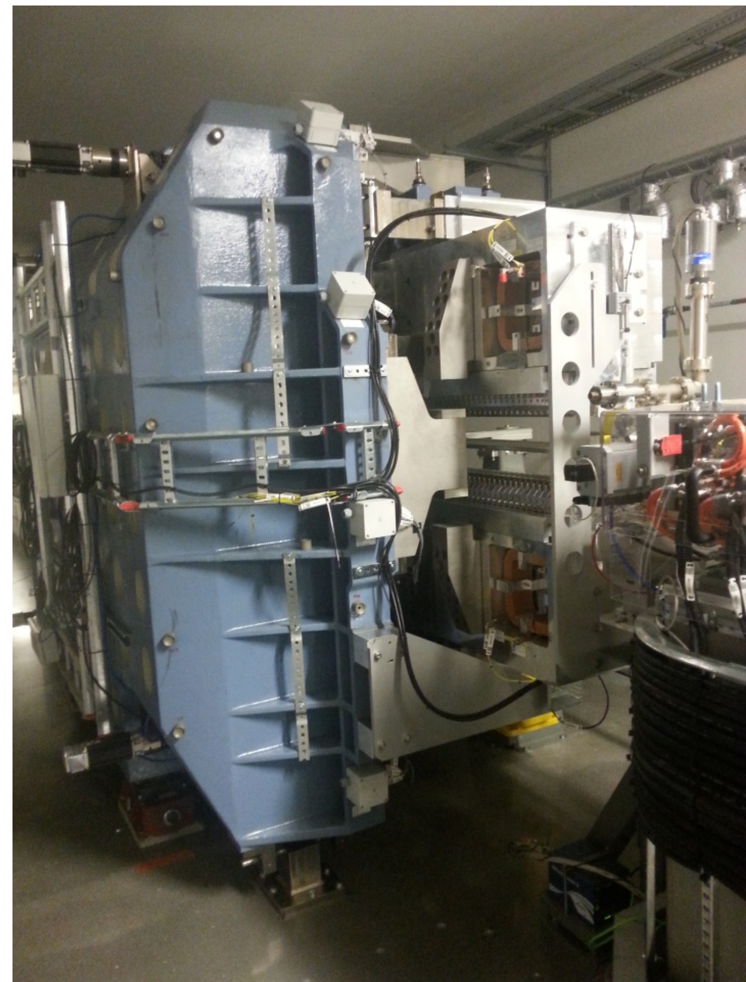
Conclusions

- Magnet lab @ MAX IV is equipped to assemble, characterize and test out-of-vacuum IDs. Investment for in-vacuum measurement capabilities is foreseen both in hardware and resources.
- New hot-water baking system and new lab infrastructure will reduce the time needed for tunnel access during ID installation.
- Five insertion devices installed in the R3 3 GeV ring and ongoing ID commissioning work follows R3 machine commissioning milestones (long bunches, high current, beam size, etc.).
- Preparation of three IDs for installation in R1 summer 2017.
- FemtoMAX Undulators installation to start after shutdown 2017.
- Five IDs are planned to be installed during 2018 (CoSAXS, DanMAX, SoftiMAX, MaxPEEM and FlexPES).

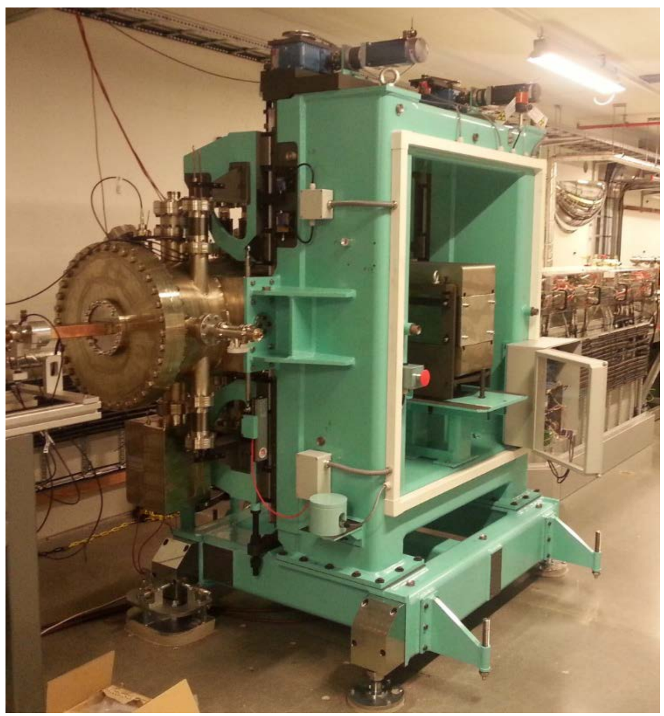
…Some Photos

BioMAX in-vacuum undulator in ring tunnel

HIPPIE EPU in ring tunnel



BALDER in-vacuum wiggler in ring tunnel



…More Photos

BLOCH EPU84 during assembly….

FinEstBeam EPU95 at the Bench…

Moving VERITAS EPU to the ring tunnel.