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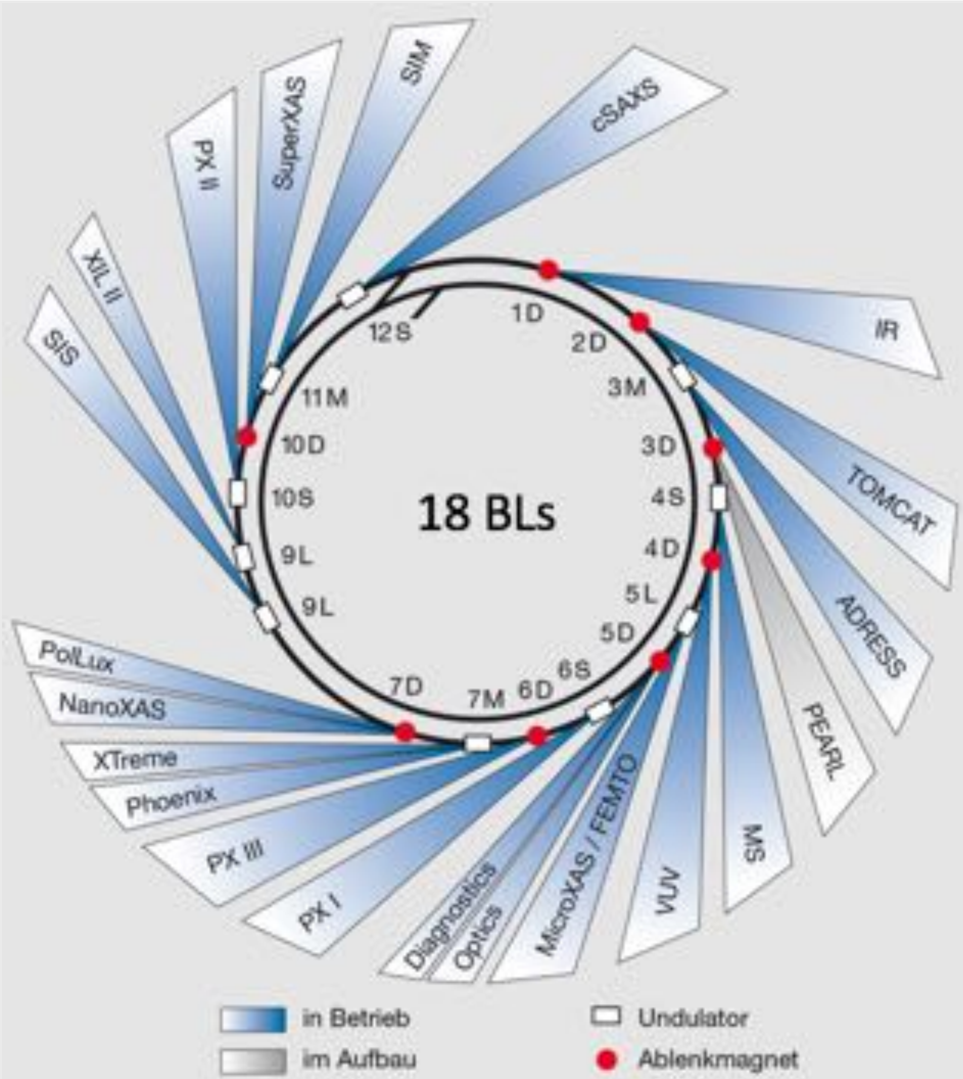
Thomas Schmidt :: Paul Scherrer Institut

Undulator for SLS and SLS-2 general

December 2017

SLS 2001 – 2017 (2023)



SLS: 2.4 GeV

4 Undulator Beamlines soft x-ray:

8 eV – 2 keV **all** full polarized.

1 Undulator Beamline tender x-ray

up to 8 keV

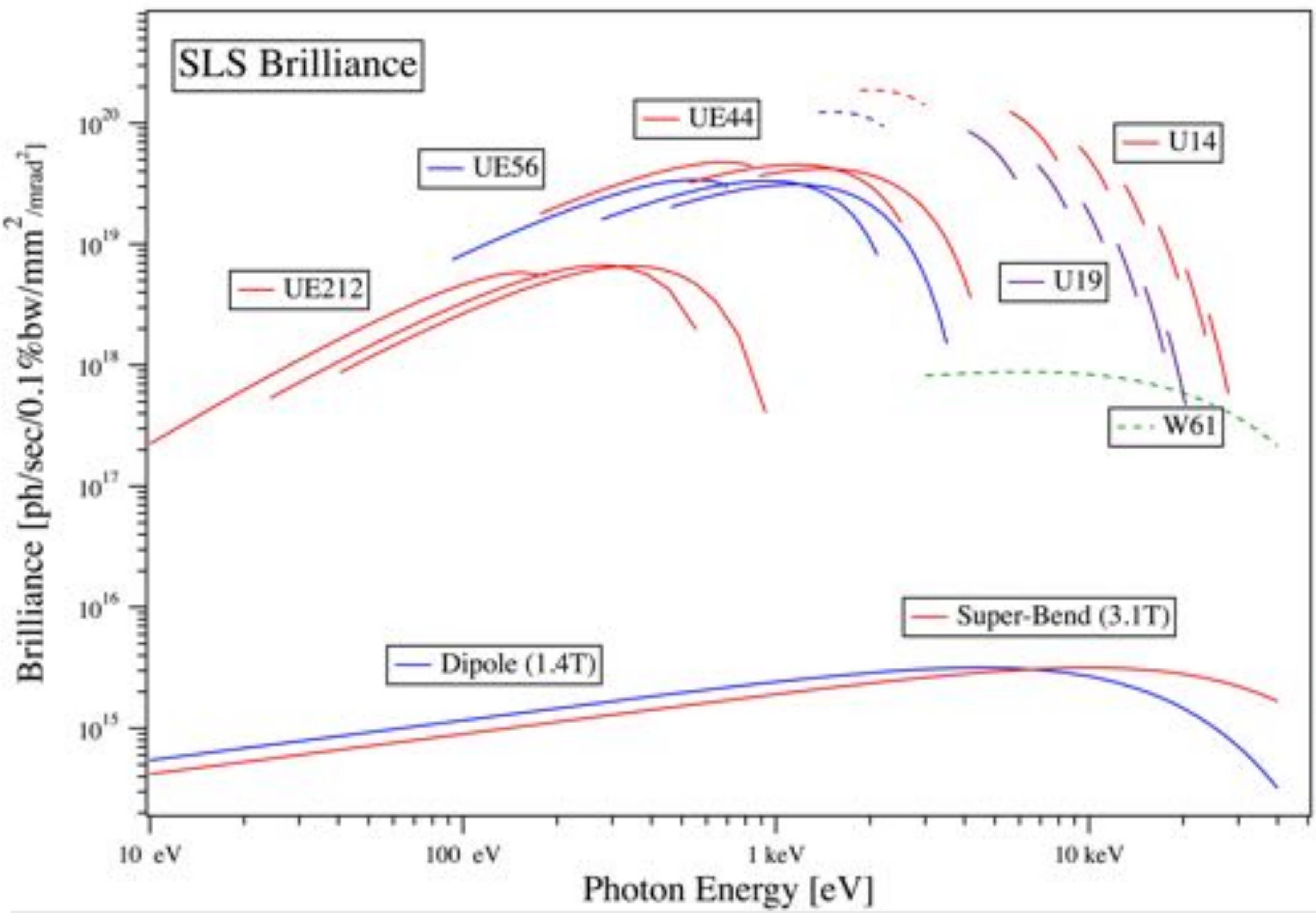
5 Undulator Beamlines hard x-ray:

5 keV – 20 keV (35keV)

5 Dipole Beamlines

3 permanent magnet Superbends

SLS Brillance



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SLS Undulators overview

ID	N	Gap [mm]	B_z/B_x [T]	K_z/K_x	N_{per}	Harm	E [keV]	Type	Magnets
SLS									
UE212/424	1	20	0.4/0.1	07.09.04	39	1-5	0.01-0.6	quasi-periodic ELM variable period	-
UE56	2	16	0.83/0.6	4.4/3.2	32	1-5	0.09-2	twin APPLE II	NdFeB
UE54	1	16	0.79/0.54	4.0/2.7	32	3-33	0,4-8	APPLE II	NdFeB
UE44	1	11,4	0.86/0.65	3.5/2.7	75	1-5	0,3-2	fixed gap APPLE II	NdFeB
U19	1	4,5	0,86	1,5	95	3-13	5-20	in-vac hybrid	Sm_2Co_{17}
U19	2	4,5	0,89	1,6	95	3-13	5-20	In-vac hybrid	NdFeB
U19	1	5,5	0,85	1,5	95	3-13	5-18	In-vac hybrid	NdFeB
U14	1	4	1,15	1,5	120	3-13	5-30	cryogenic in-vac	NdFeB
SwissFEL									
U15	13	3	1,28	1,8	265	1	2-12*	In-vac Dy enhanced	NdFeB
UE40**	26	3	1.05/1.05	3.8/3.8	40	1	0.18-1.8*	APPLE III	$SmCo_5$

* incl. e^- energy

** design phase

SLS & SwissFEL: concept

SLS 2.4 GeV

soft x-ray variable polarization

APPLE II

twin UE56 (<- BESSY II)

UE54 soft & tender x-ray

fixed gap UE44

quasi-periodic elm

hard x-ray

in - vacuum (<- SPring-8)

work horses: U19 -> 20keV

CPMU U14 -> 35keV

gap min = 4mm, 2m long

2.9 - 3.4 GeV **SwissFEL** 2 - 8 GeV

soft x-ray variable polarization

APPLE-X (DELTA II)

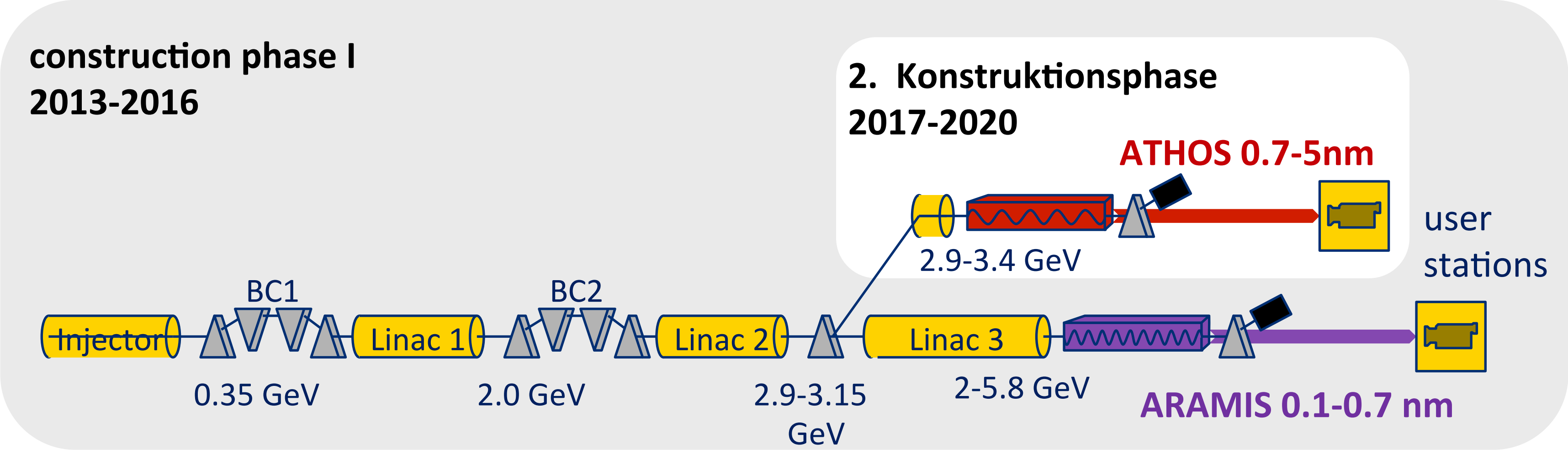
UE38, Chic Modes

in - vacuum

U15 3mm, 4m long -> 12keV

U10 sc ?! (2025 ff) -> 36keV

SwissFEL in a nutshell



Aramis

Hard X-ray FEL, λ=0.1-0.7 nm

Linear polarization, variable gap, in-vacuum Undulators

First users 2017

Athos

Soft X-ray FEL, λ=0.65-5.0 nm

Variable polarization, Apple undulators

First users 2020

Main parameters	
Wavelength from	1 Å - 70 Å
Photon energy	0.2-12 keV
Pulse duration	1 fs - 20 fs
e^- Energy	5.8 GeV
e^- Bunch charge	10-200 pC
Repetition rate	100 Hz

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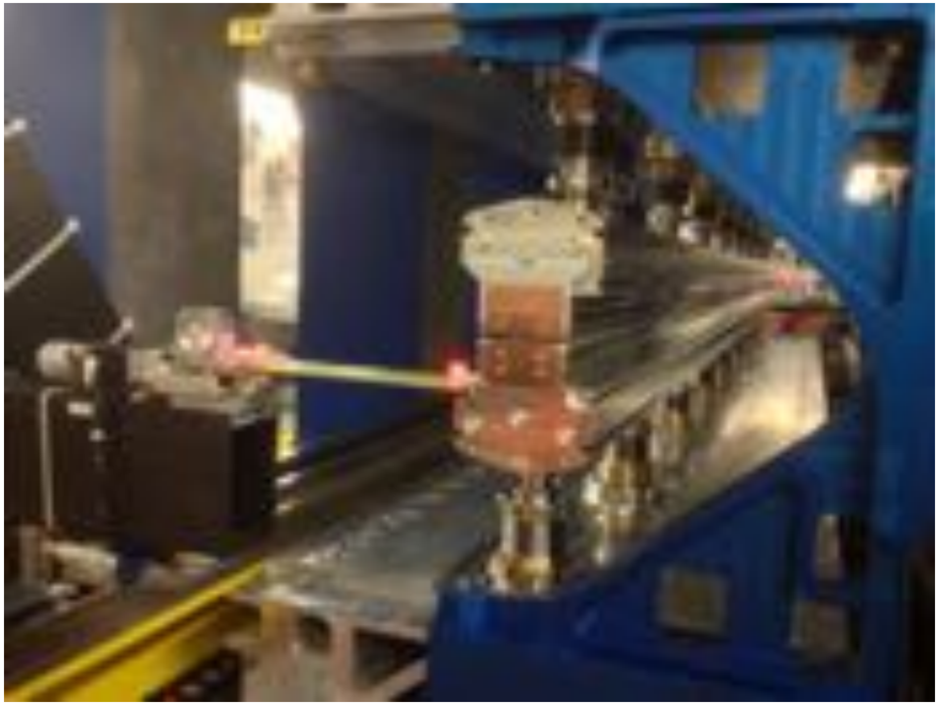
SwissFEL ARAMIS U15

SwissFEL: Aramis U15

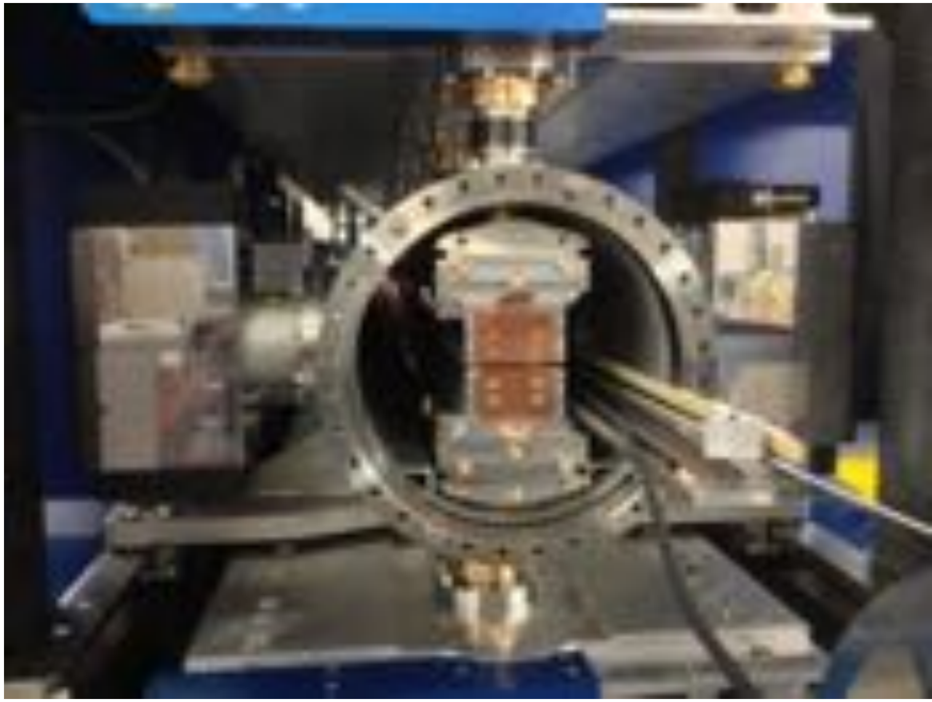
PSI measurement benches

Laser based SAFALI Measurement systems[1]:

1st without tank: trajectory and phase
2nd inside tank: phase and calibration field vs gap



Senis Hall probe, linear motor
laser based axes stabilization
Juri 2.0



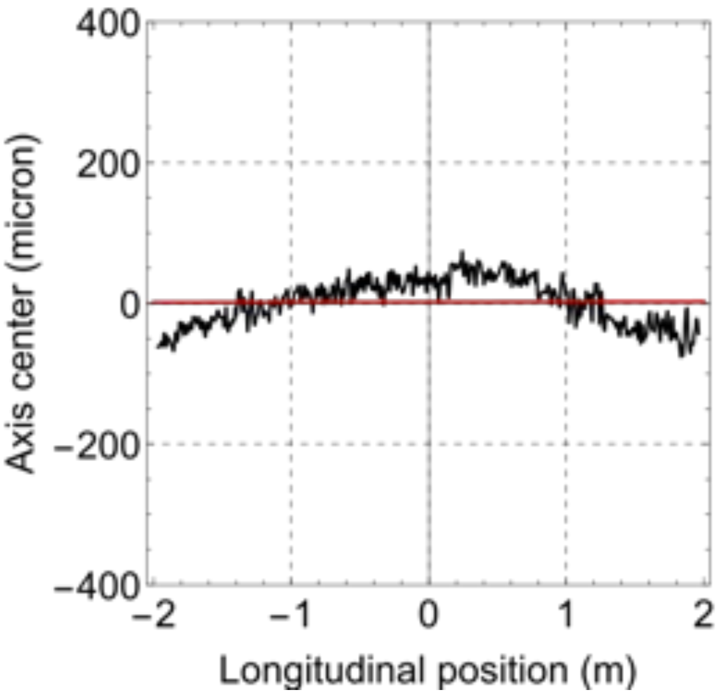
Senis Hall probe, piezo stepper
laser based axes stabilization

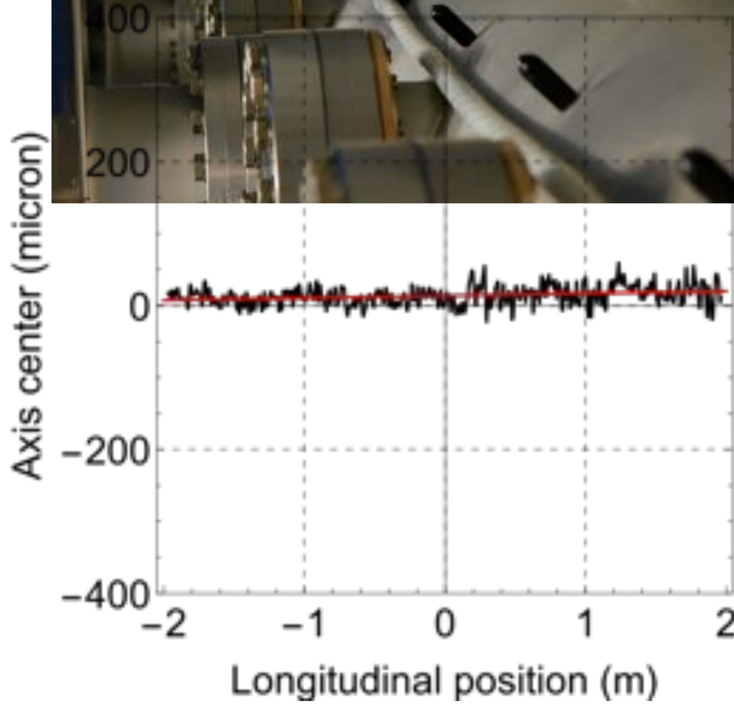
[1] SAFALI concept by T. Tanaka

U15 optimization step 1: center the axis

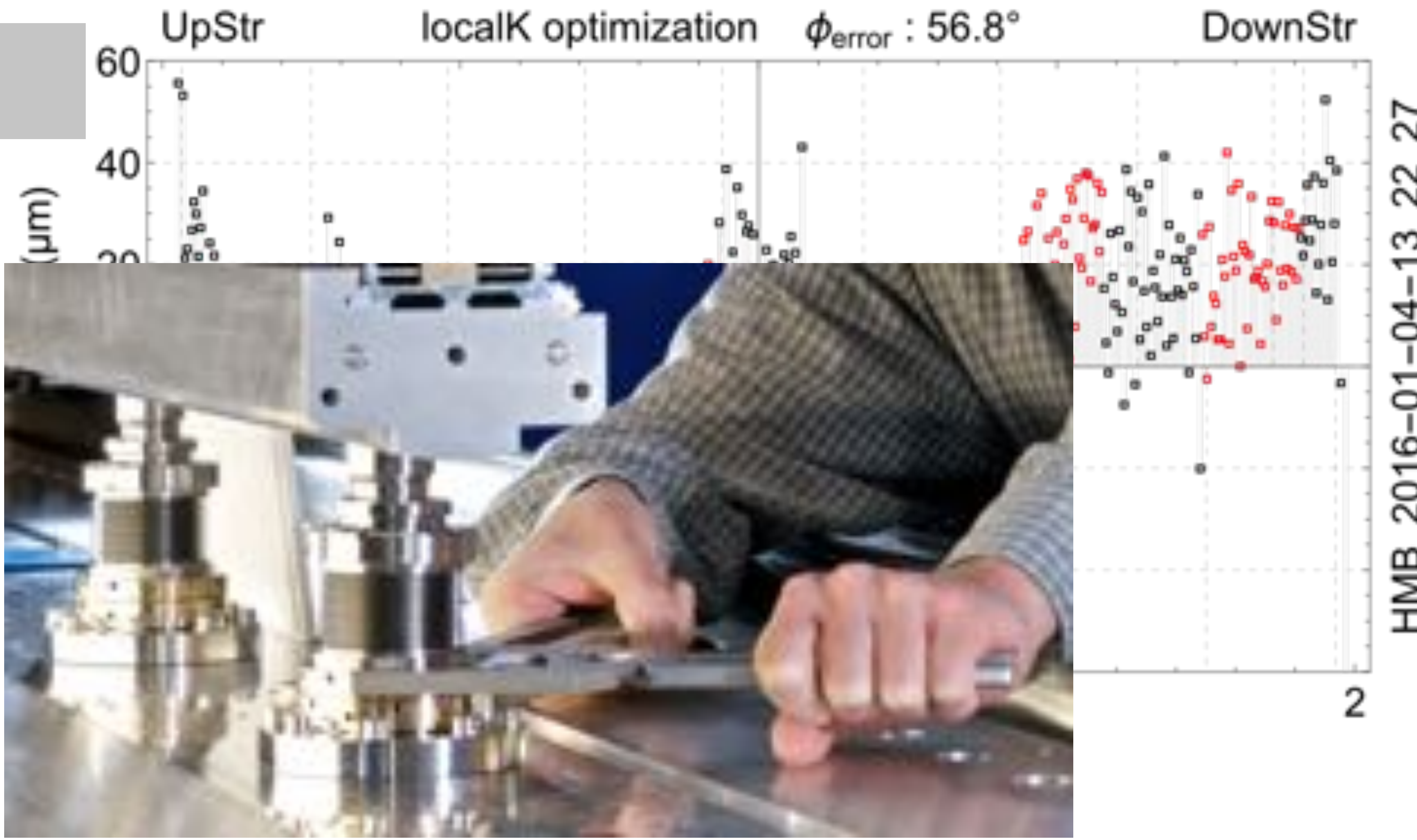
measure axial B

differential screws in columns





U15 opt. step 2: long range errors



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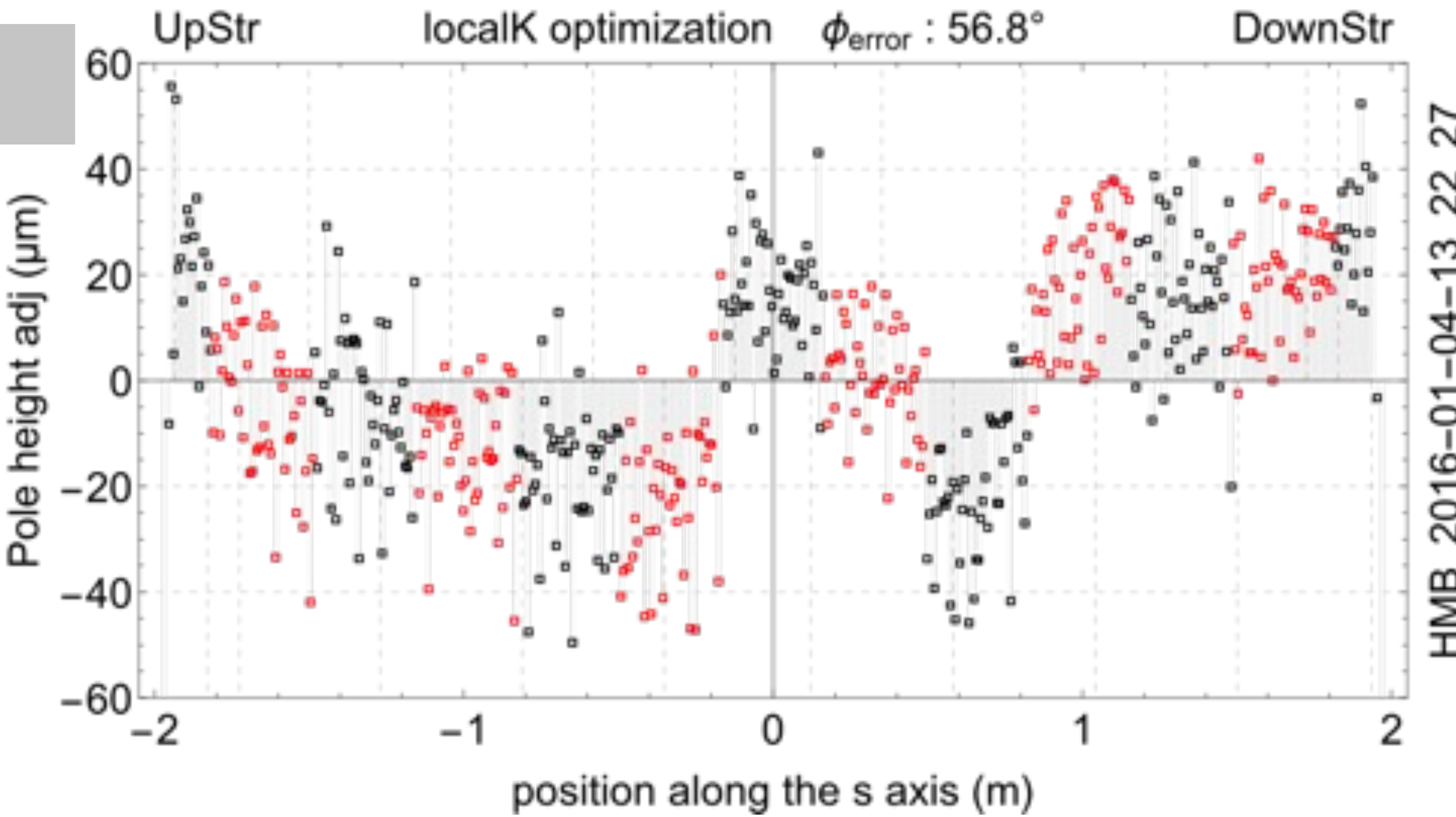

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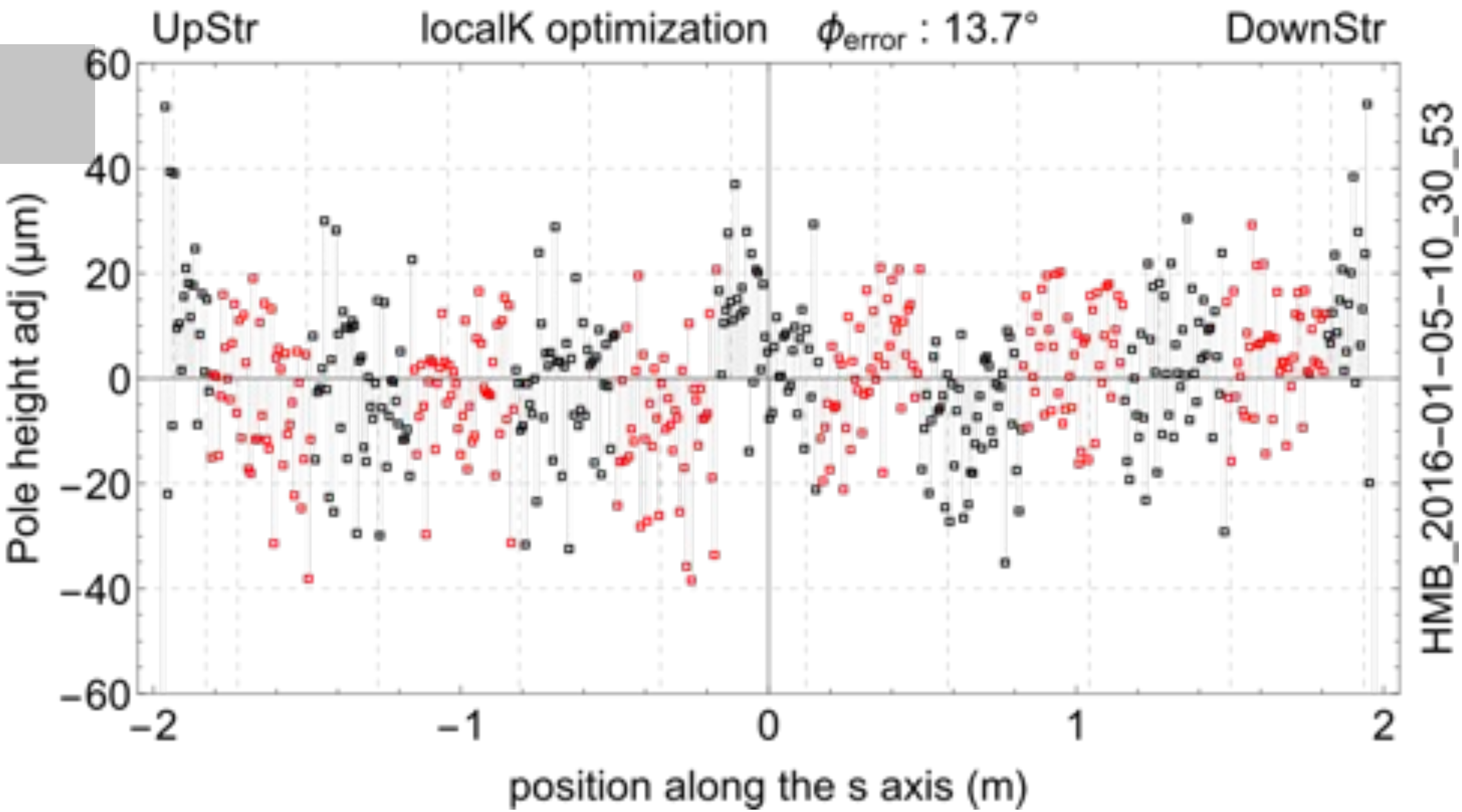
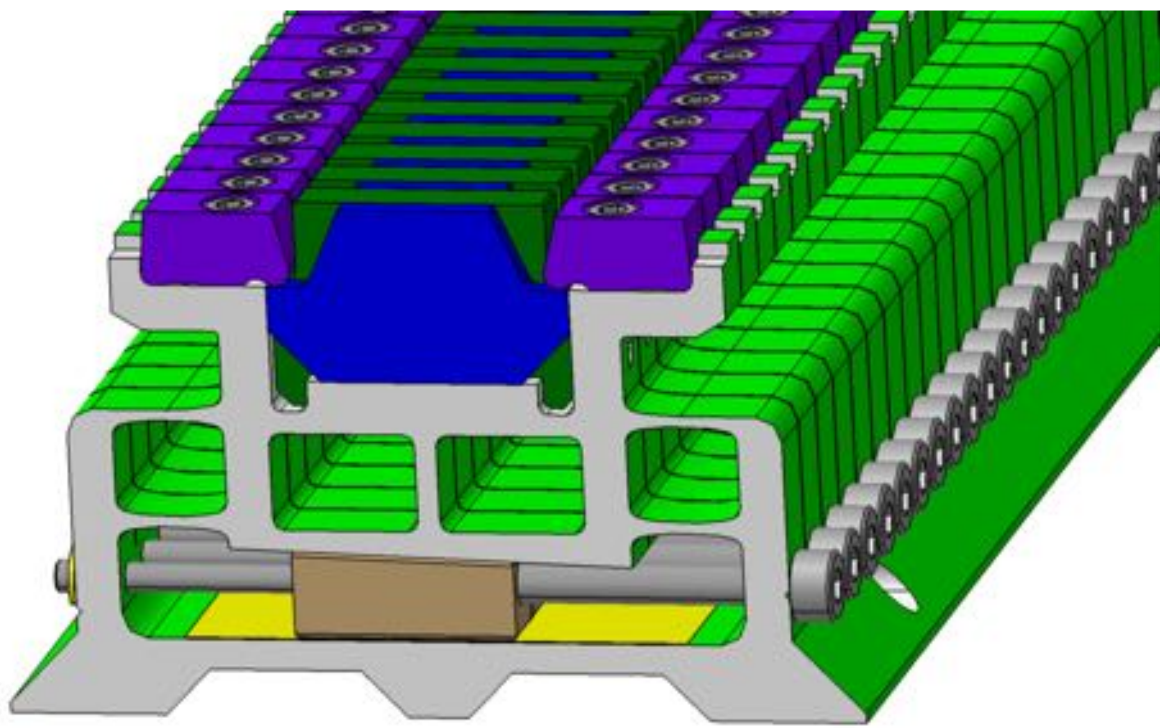


U15 opt. step 3: local errors

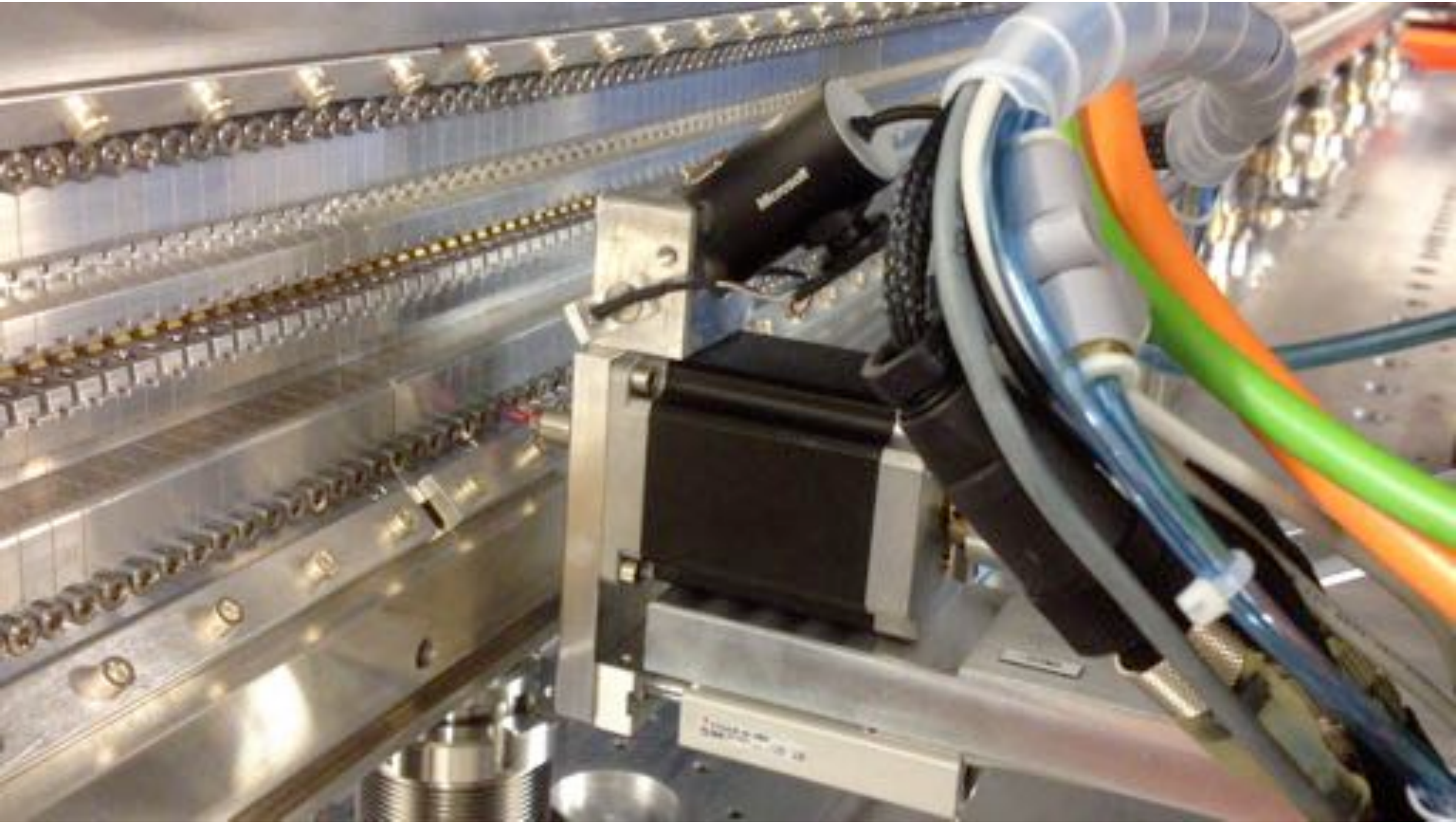
block keeper

flexor design

precise tuning with adjustable wedge

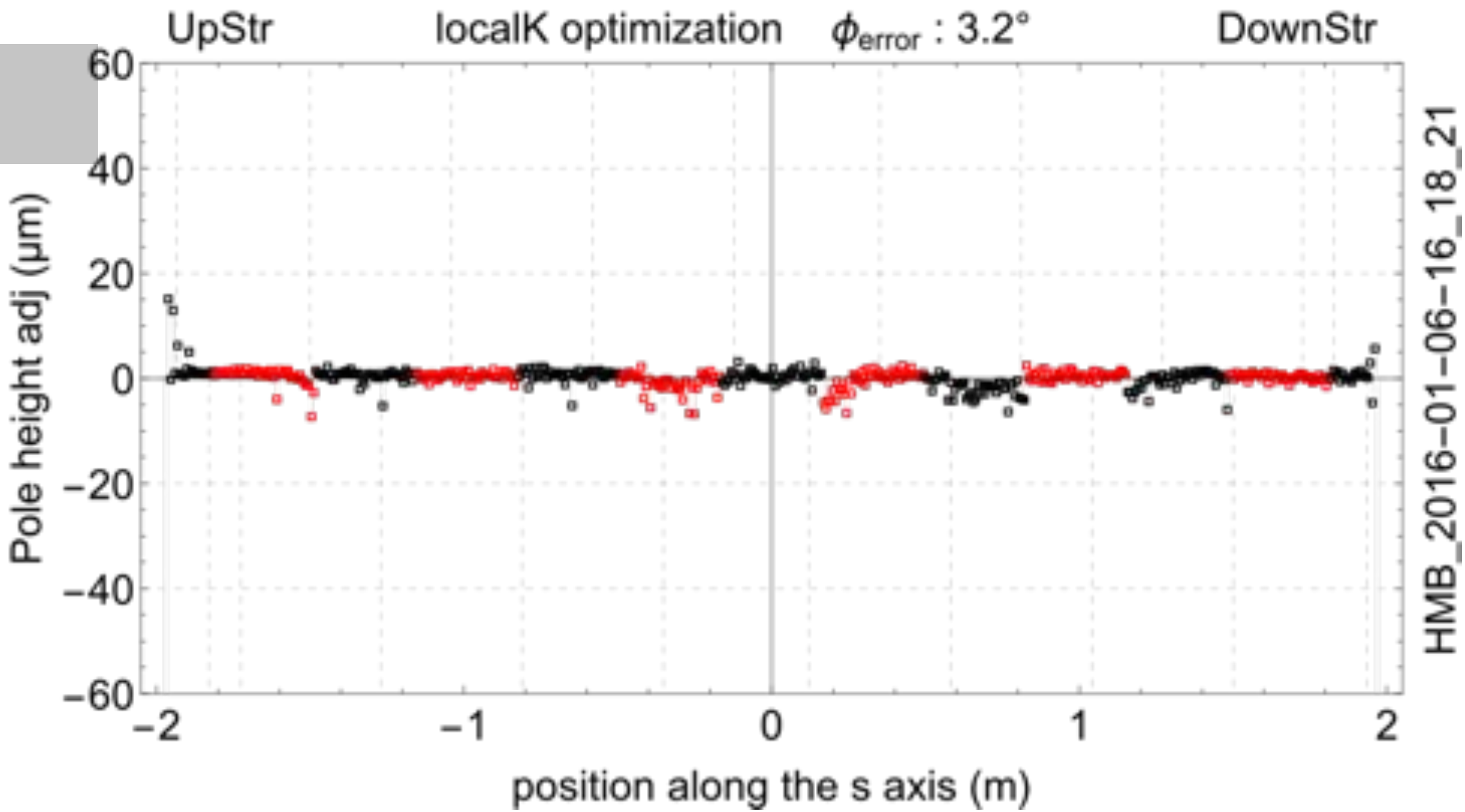


U15 opt. step 3: local errors



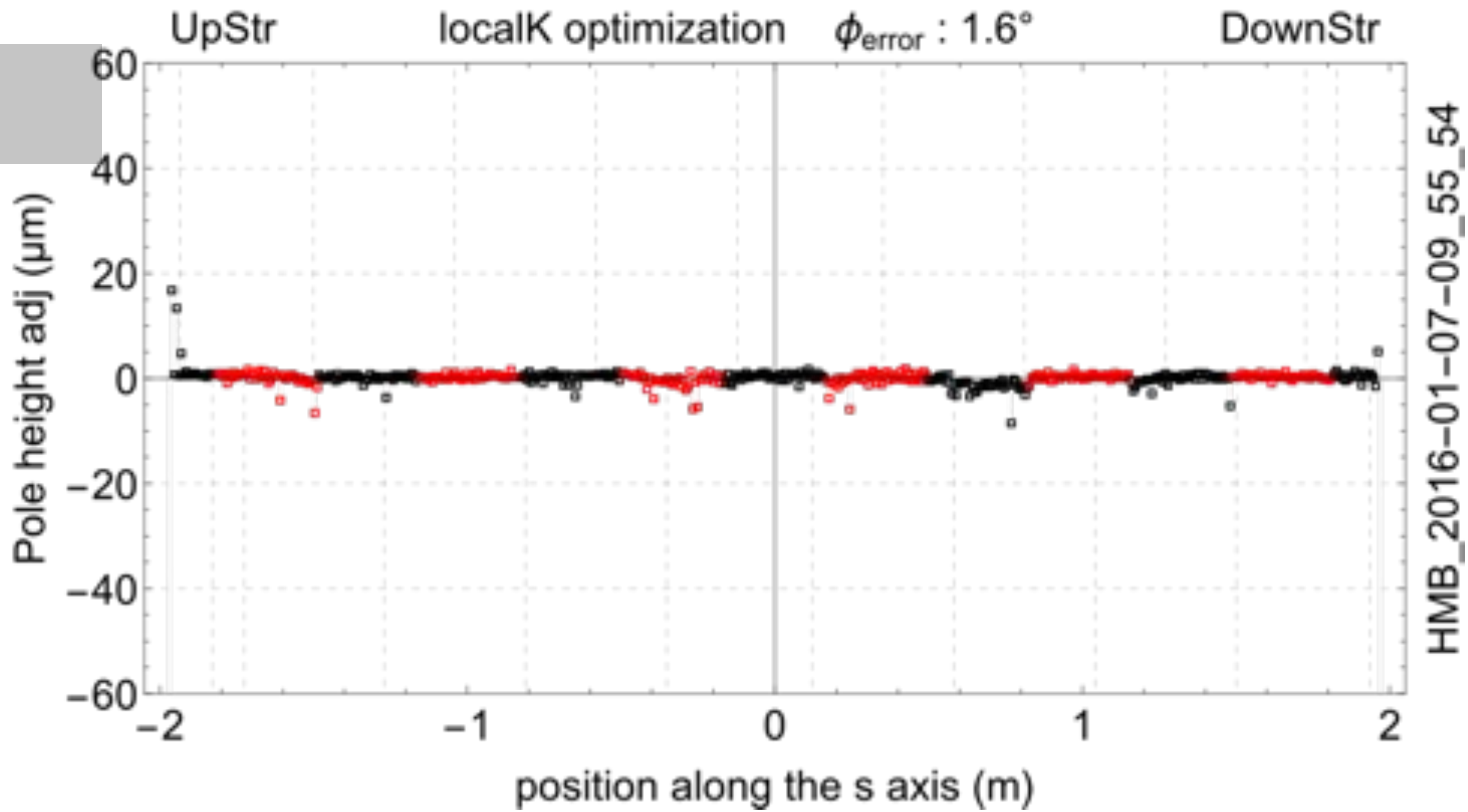
Yuri 2.0 automated optimization

U15 opt. step 3: local errors



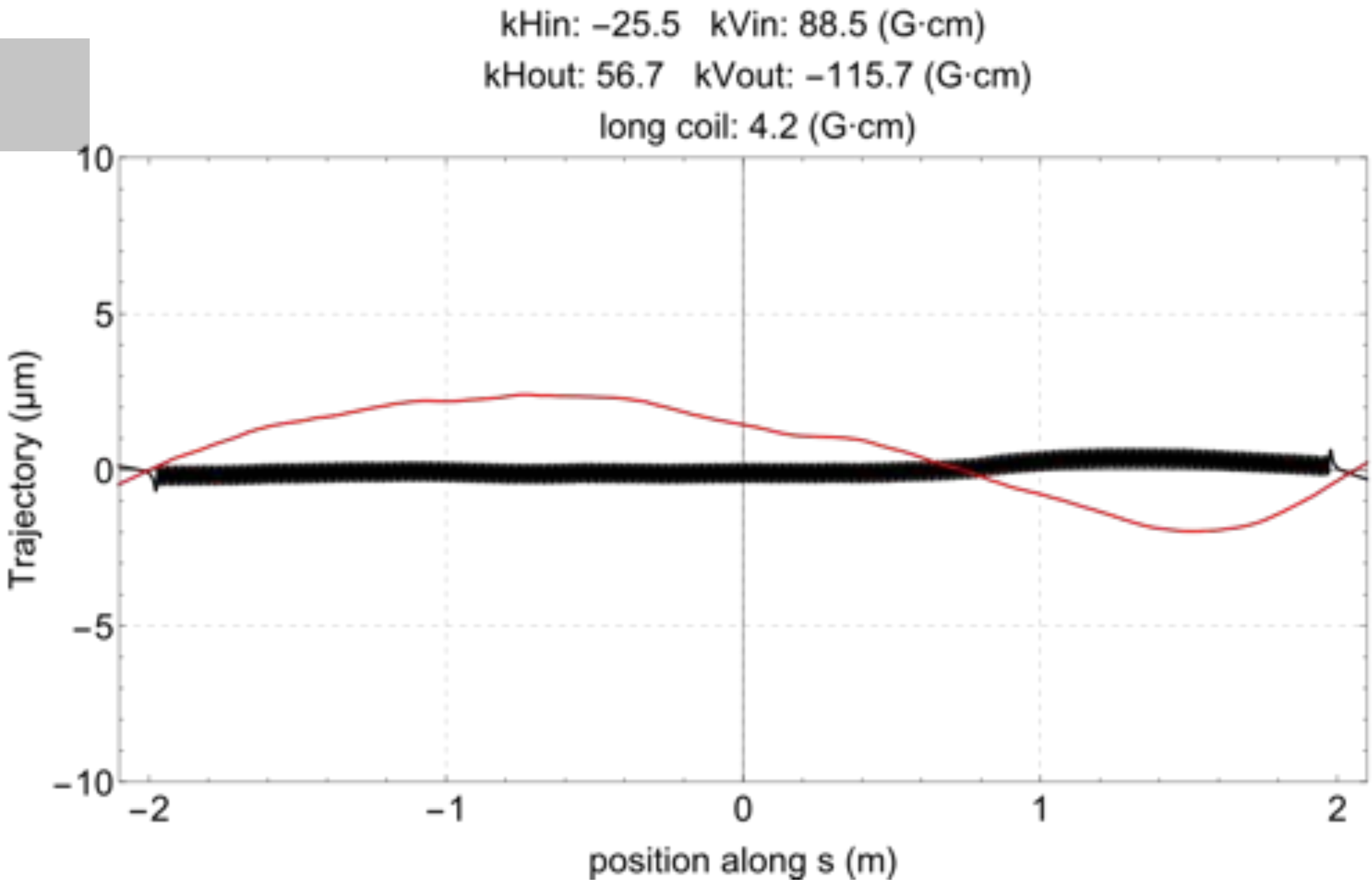
after 1st Yuri run

U15 opt. step 3: local errors

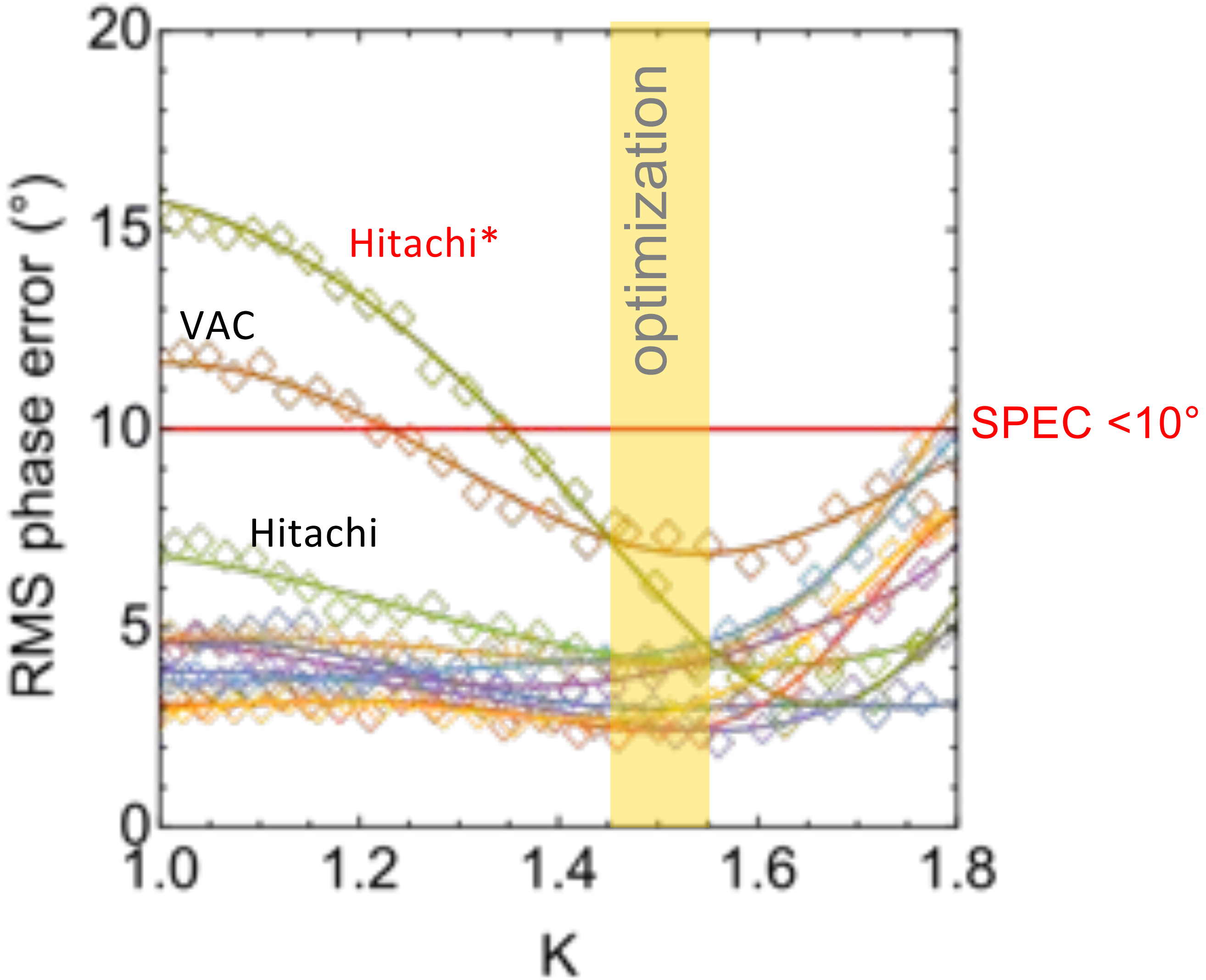


after 3rd Yuri run

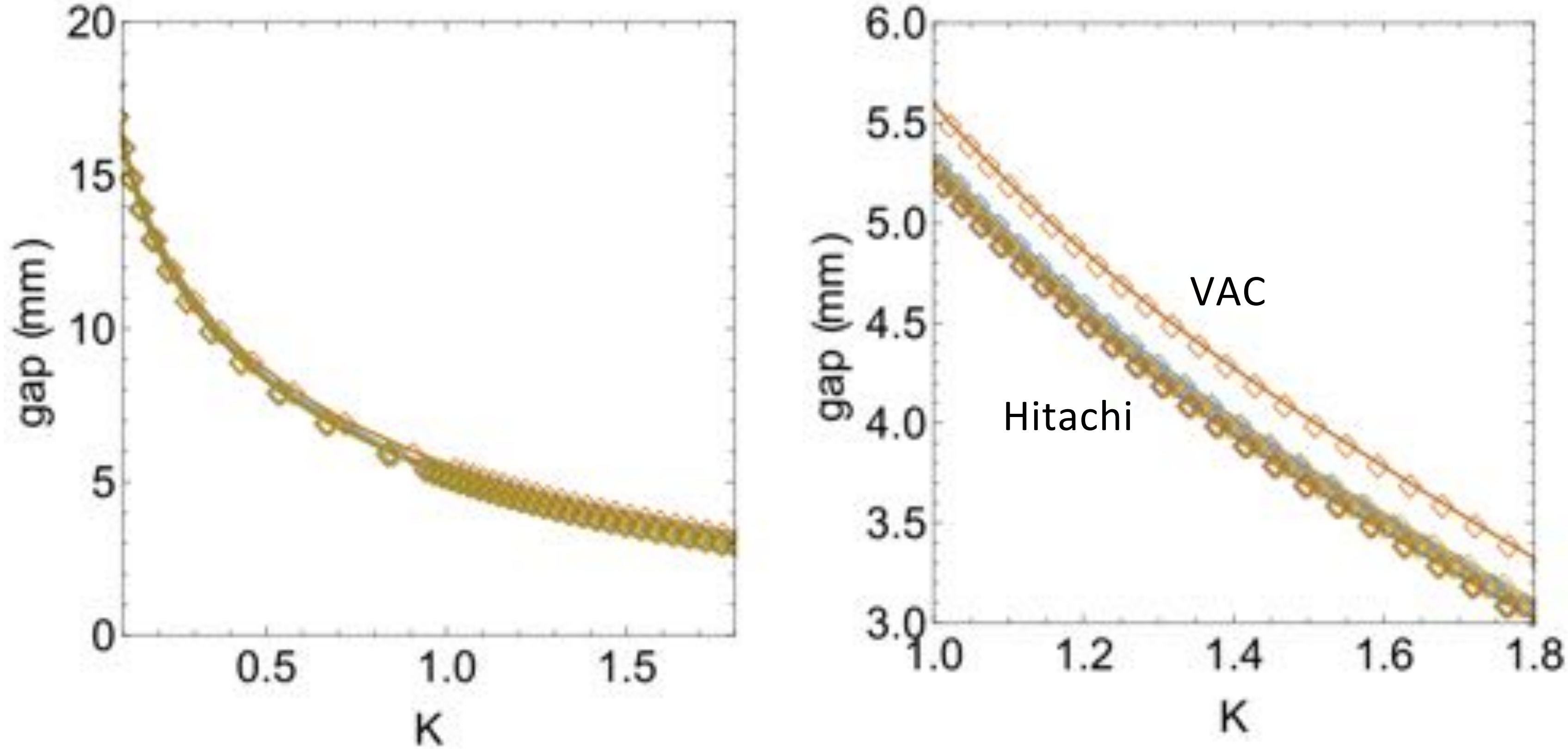
IDs for SwissFEL: Aramis U15



Aramis U15 Series Performance

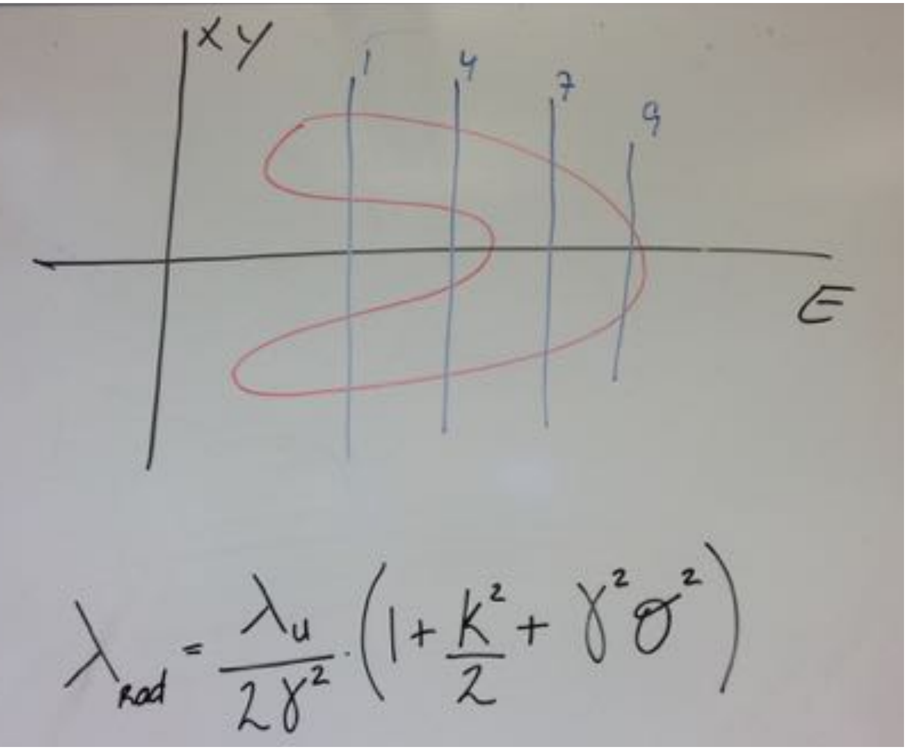


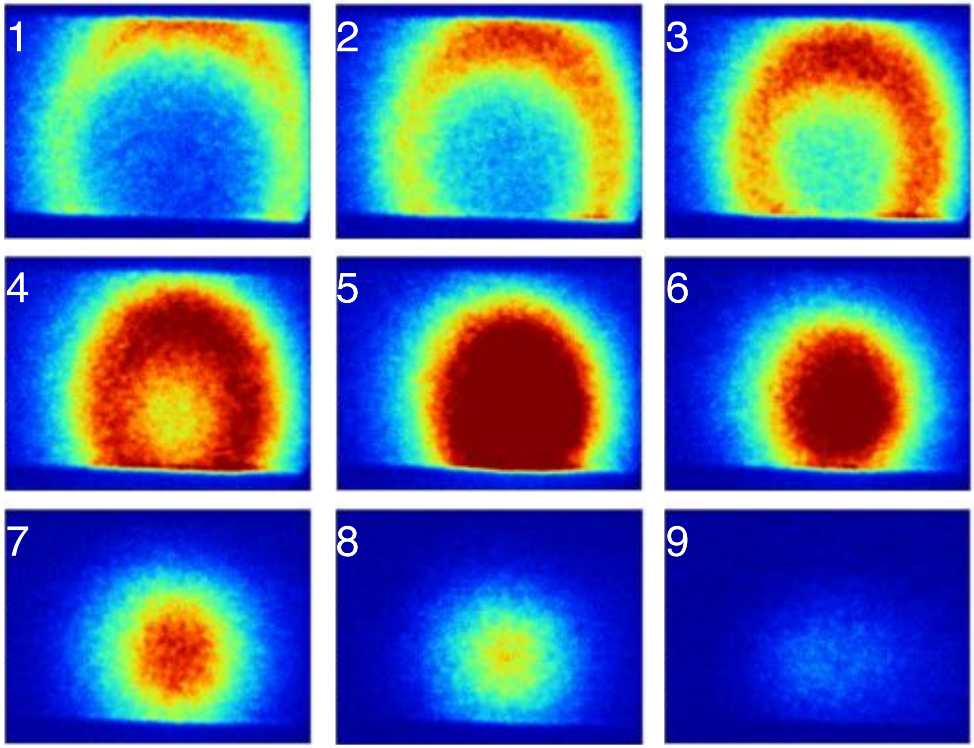
Undulator Performance: magnet strength



U15 spontaneous radiation

- Monochromator Energy Scan over the third harmonic, from 6345eV to 6465eV, in steps of 15eV, using Si111 crystals.
- SR from SARUN15 observed on MCP at K = 1.2





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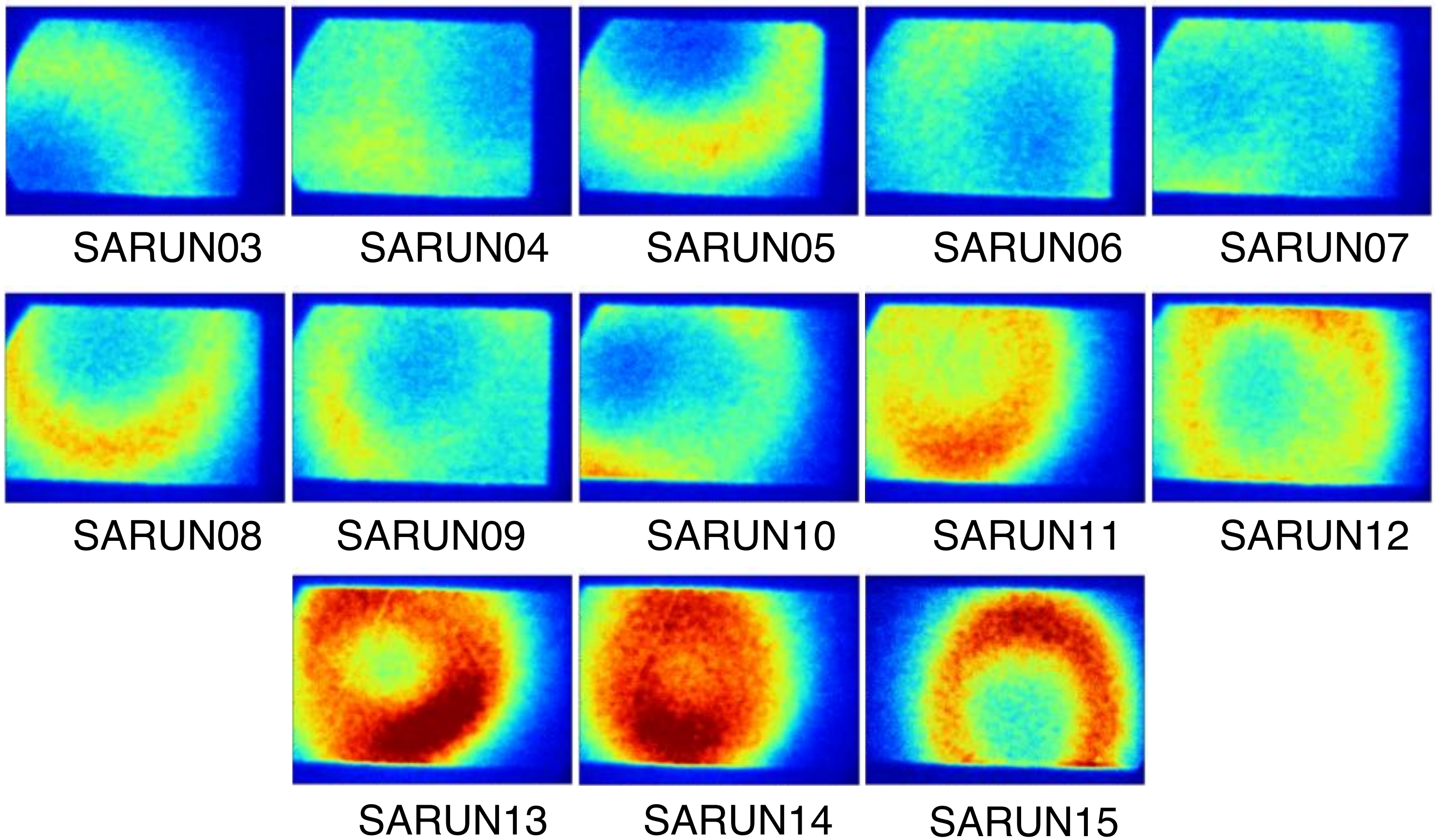
Individual Pointing Direction

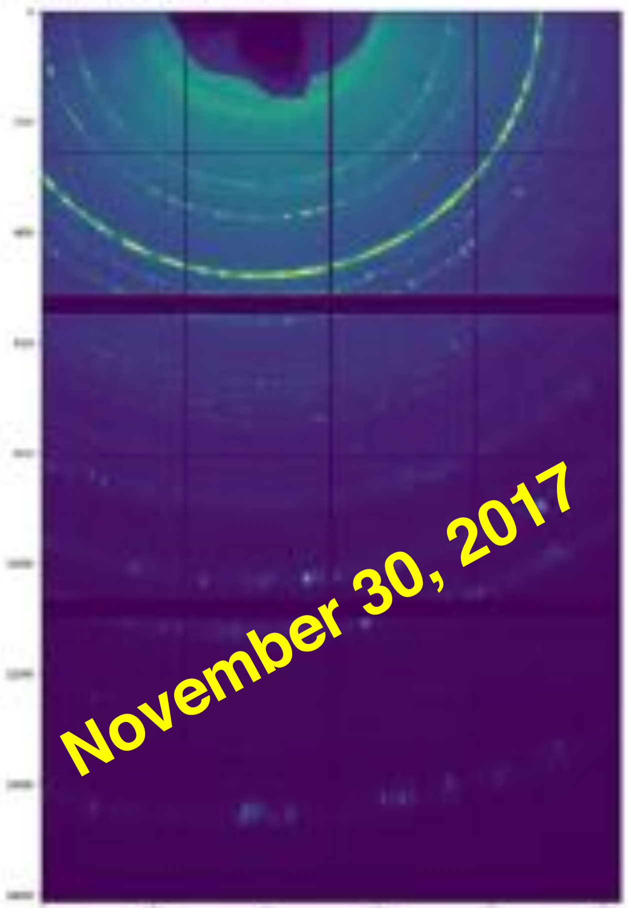
- Undulator being measured set to K = 1.2, with the rest at K = 0.072 (full open)
- The monochromator was set to 6375eV, third harmonic, using Si111 crystals.



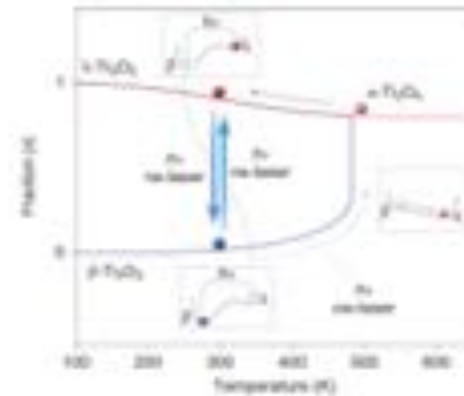
Need to fine adjust K and electron trajectory in the individual undulators

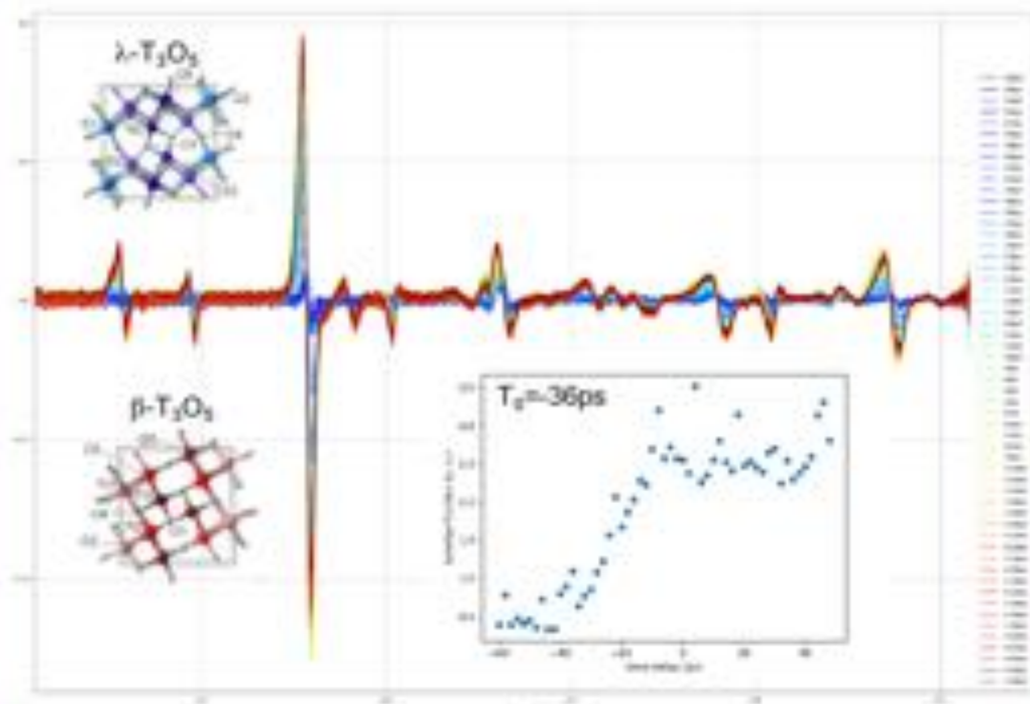
First time resolved Pilot Experiment by SwissFEL: Semiconductor to metal transition in Ti3O5 nanocrystals

Collaboration:
SwissFEL and M. Cammarata et al.,
Univ. Rennes

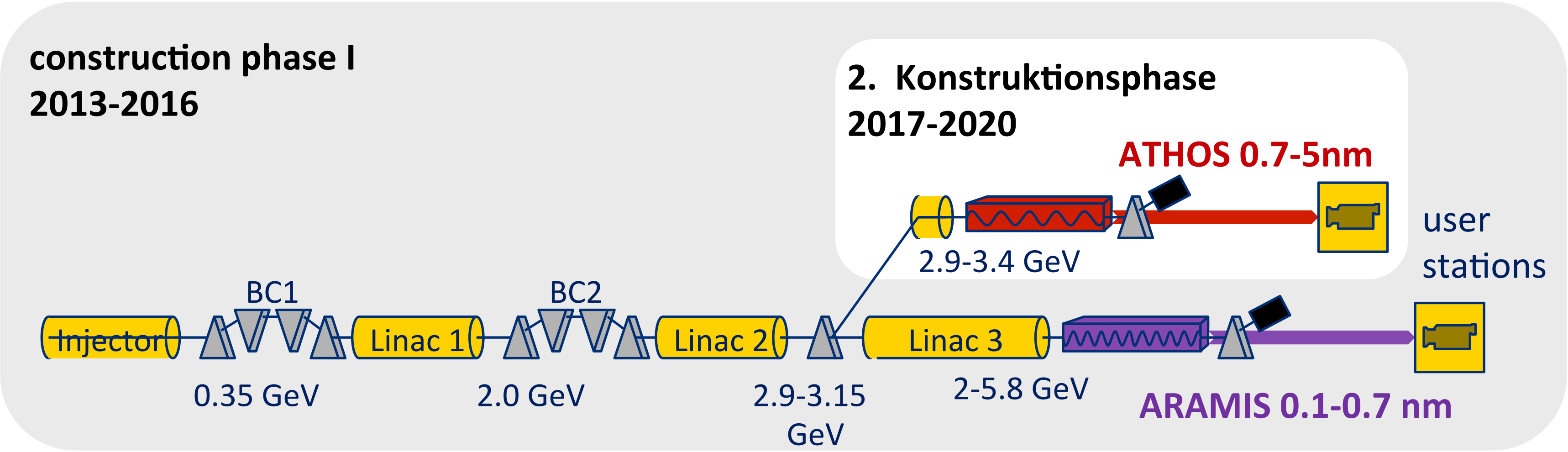


-3rd Harm: 6.6 KeV
(fund. 2.2 KeV 220 μJ)
-Laser: 800nm, 42 mJ/cm^2





SwissFEL in a nutshell



Aramis

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- Linear polarization, variable gap, in-vacuum Undulators
- First users 2017

Athos

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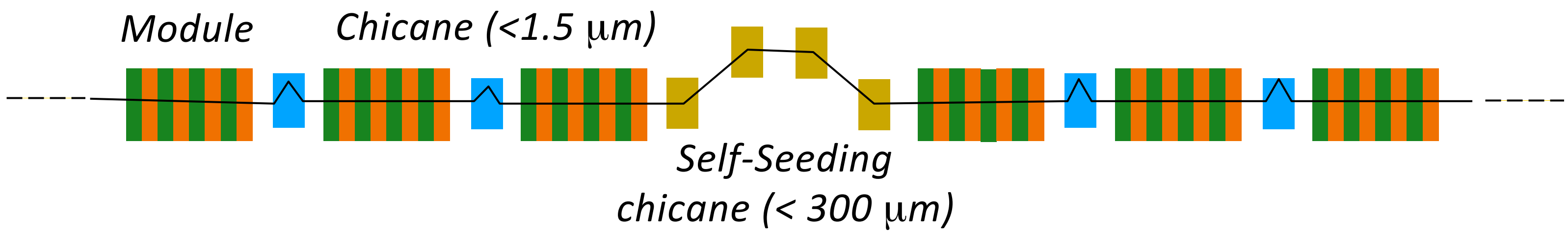
Overview of Athos Operation Modes



Basic Modes + Enhancement

- SASE
- Optical klystron
- Harmonic lasing

Special Modes

- High-power and short pulses*
- Two color*

Spectral Control

- High-brightness SASE
- Large bandwidth mode*
- Self-seeding

External Synchronization

(requires external laser, not available yet)

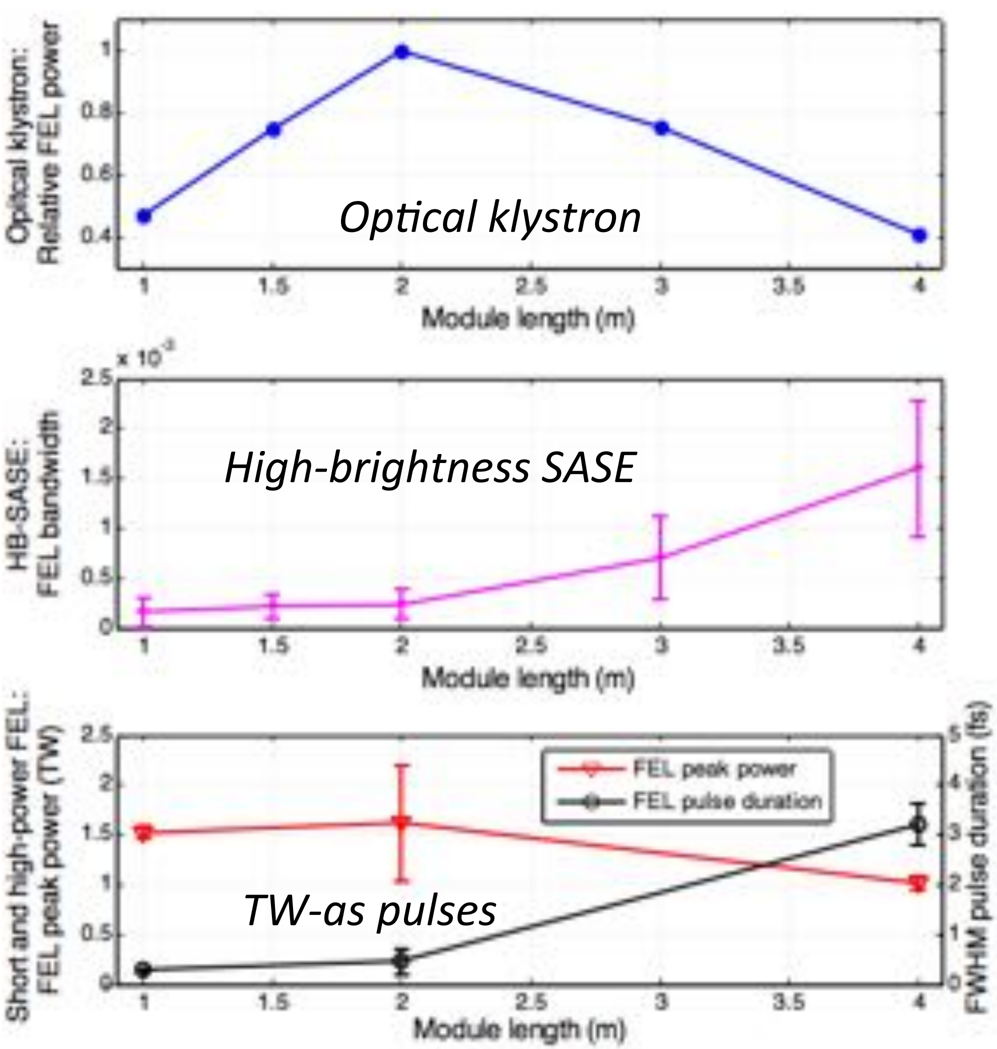
- Mode-locked lasing
- Slicing
- HHG seeding

Legend:

APPLE-X Configuration *Tilt** *Chicanes* *Self-seeding chicane* *Baseline* *Not Baseline*

Optimization of undulator module length

Summary of FEL performance as a function of the undulator module length

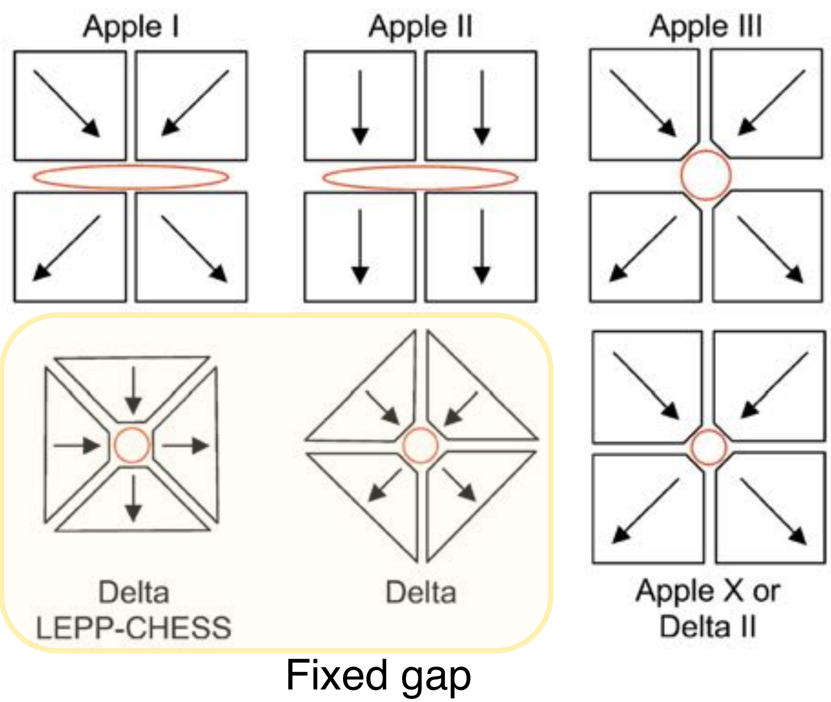


[E. Prat et al, JSR 23, 861 (2016)]

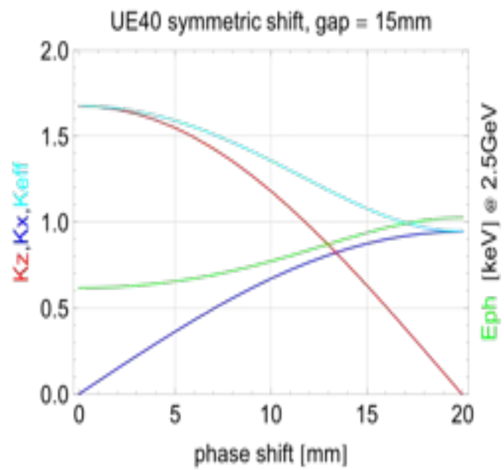
- In most of FEL facilities, the module length is not optimized based on FEL performance
- Typical undulator module length is about 3-5 m for robust operation
- Most of the modes benefit from shorter modules.

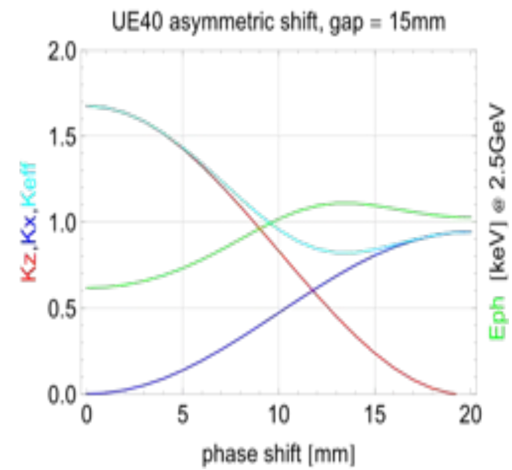
Based on physics and costs
Final module length is 2 m
(in original design was 4 m)

APPLE history

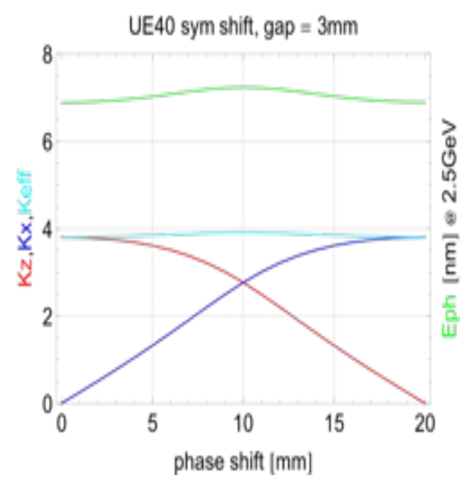


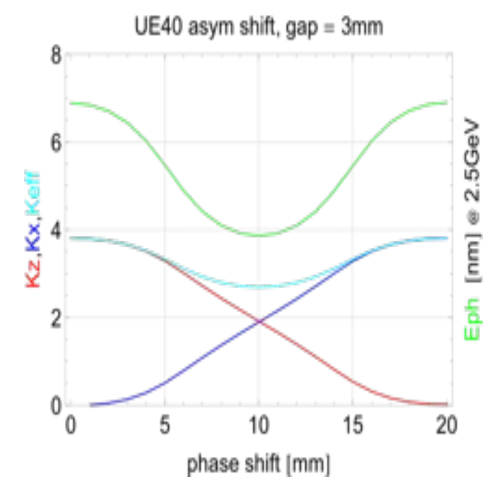
APPLE II





APPLE X





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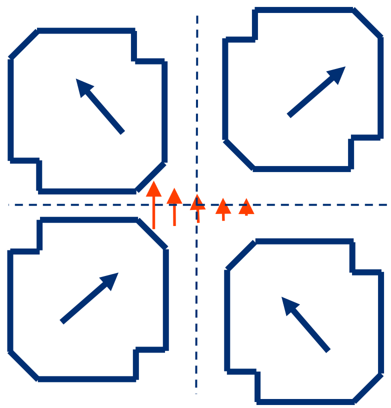
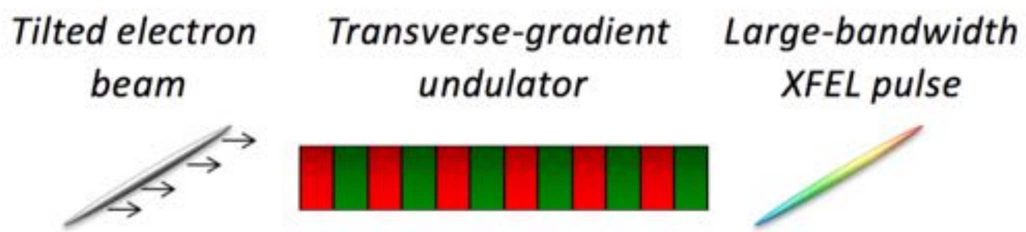
APPLE X advanced modes I





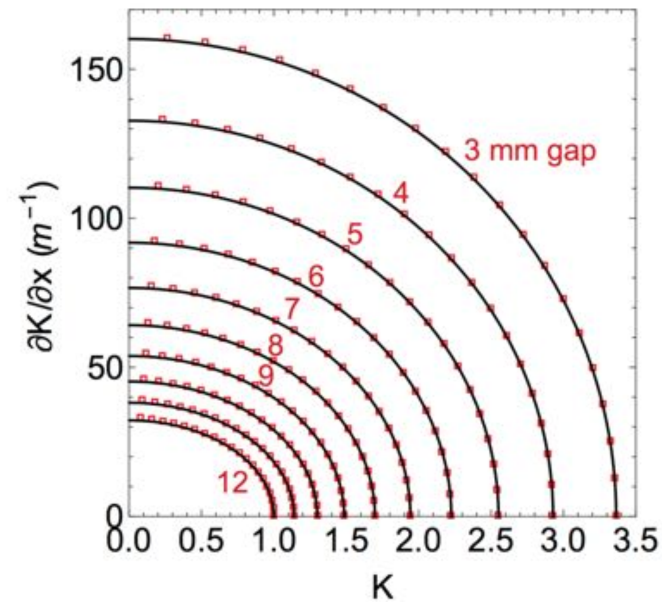


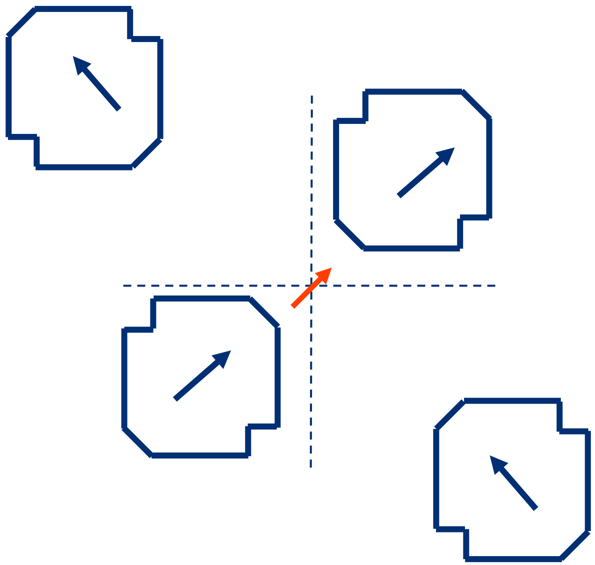
Fig. 5. Horizontal component of the K gradient versus K for different gaps. The lytical model (solid line) is presented together with the computer simulation n with RADIA (red square markers).

transverse gradient undulator

tapered undulator (with yaw by cam-shaft movers

M. Calvi et al, Transverse gradient in Apple-type undulators, J. Synchrotron Rad. (2017). **24**, 600-608

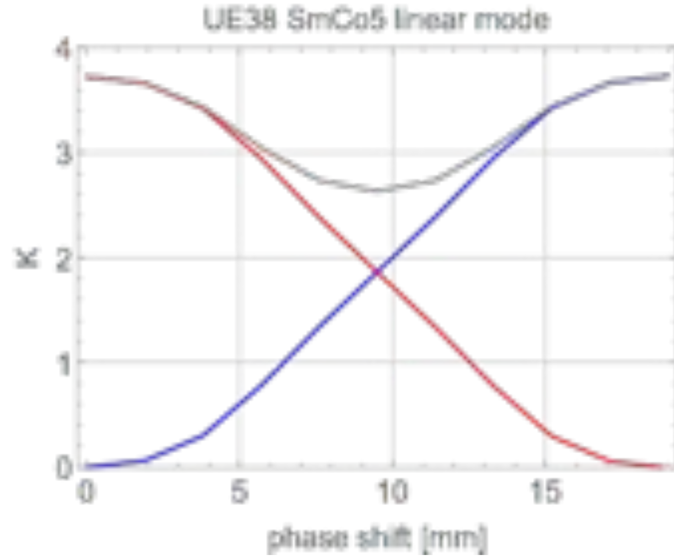
APPLE X advanced modes II

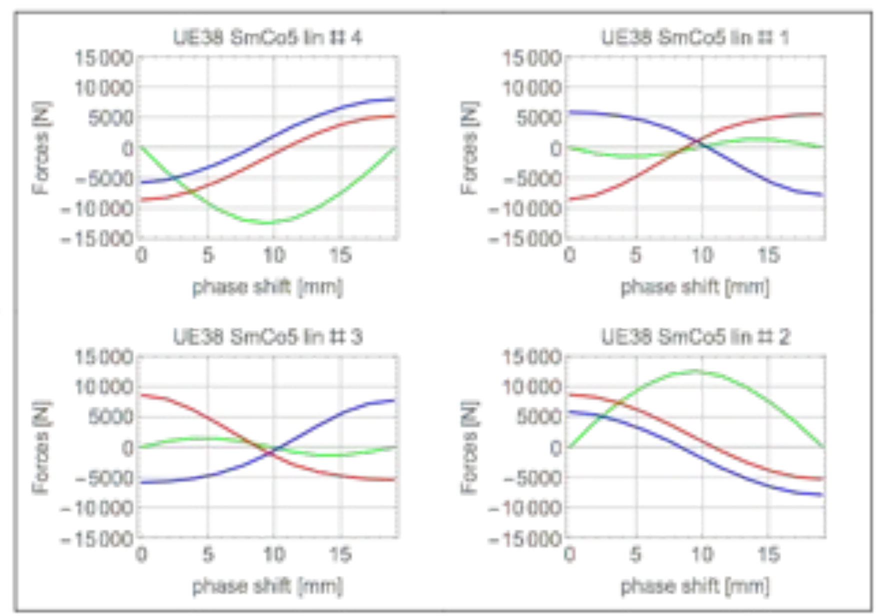


45° linear polarization in standard APPLE (II or X) operation has longitudinal forces (green)

the mode above gives 45° without any longitudinal forces

proposed by EUXFEL





APPLE X operation
Full control on fields & gradients

Full symmetry

$$\hat{B}_{x1} = \hat{B}_{y1}$$

$$\partial_x \hat{B}_{x1} = \partial_y \hat{B}_{y1}$$

Full control of

- Energy
- Polarization
- Gradients

circular

$$K = 4\kappa \hat{B}_{x1} \cos \tfrac{1}{2}\phi_{\mathrm{e}}$$

$$\partial_x K = G_0 \left(1 - \xi^2\right)^{1/2}$$

$$\kappa = \frac{e\lambda_{\mathrm{U}}}{2\pi mc}$$

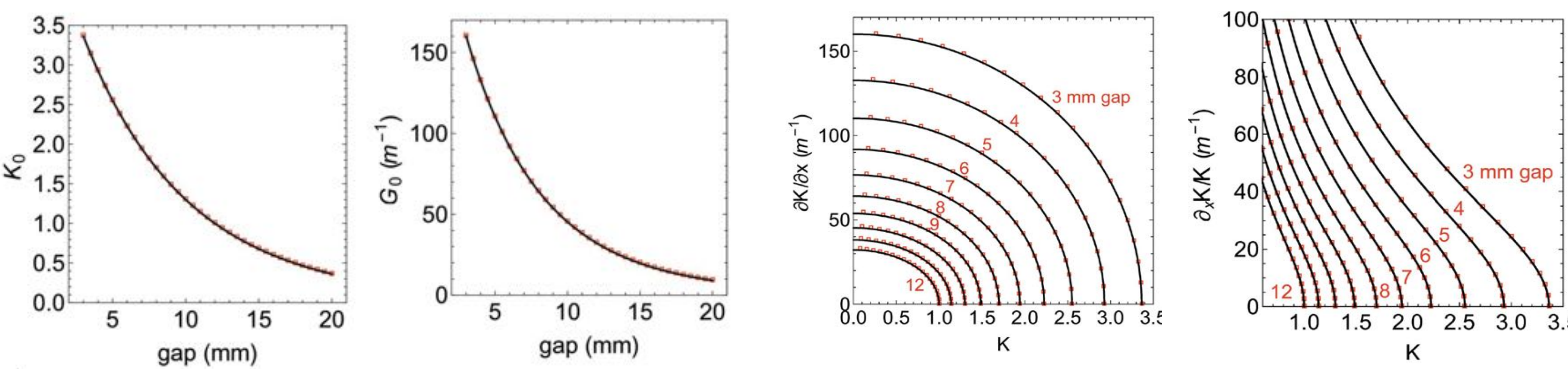
$$G_0 = 2\kappa\left(\partial_x \hat{B}_{1x} - \partial_x \hat{B}_{1y}\right)$$

$$\xi = K/K_0$$

inclined

$$K = 2\kappa \hat{B}_{1x}\left[2 + \cos\phi_{\mathrm{e}} + \cos\left(\phi_{\mathrm{e}} \pm 2\phi_{\bar{\mathrm{p}}}\right)\right]^{1/2}$$

$$\partial_x K = 0$$



M. Calvi et al., Transverse gradient in Apple-type undulators, J. Synchrotron Rad. 2017, **24**, 600-608

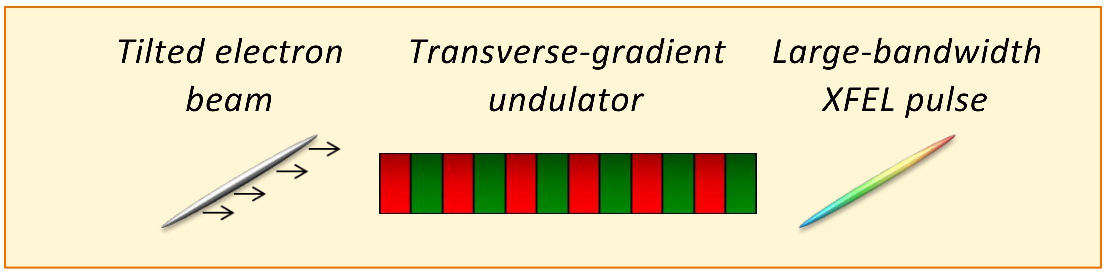
Spectral control: bandwidth increase

In a TGU there is a dependence of the undulator field on the transverse position

$$\frac{K(x) - K_0}{K_0} = \alpha x$$

K_0: on-axis field
α: gradient

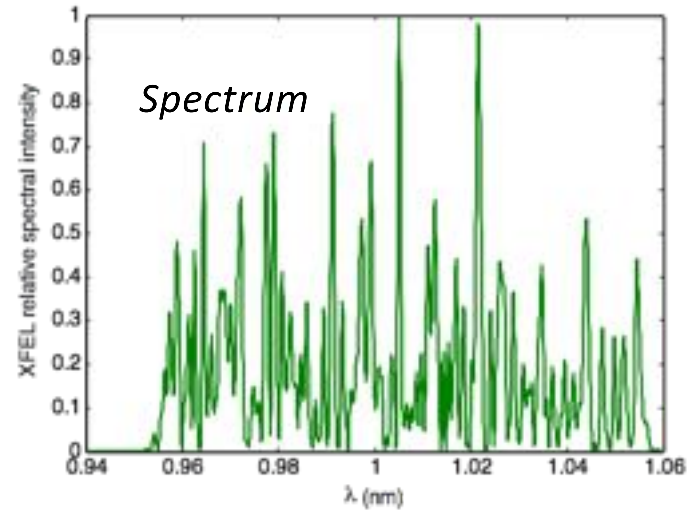
A tilted beam traveling through a TGU will produce broadband XFEL radiation. Easy to tune!

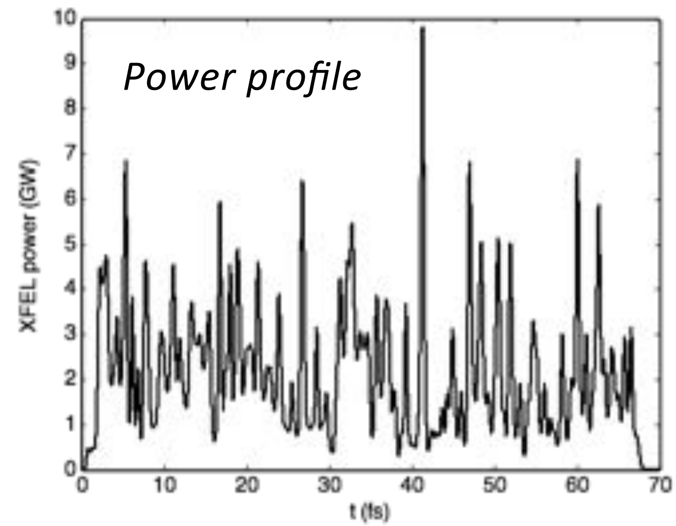


[E. Prat, M. Calvi, and S. Reiche, JSR 23, 874 (2016)]

- Additional possibilities of the scheme:
  - Multiple colors with slotted foil at the undulator entrance
  - FEL pulse compression (sign of the chirp can be controlled)
- Alternative method: energy-chirped electron beam + optimize laser distribution at the source. Results: ~3% bandwidth for 0.1 nm and 5.8 GeV @ Aramis

Simulations (10% bandwidth)





XFEL pulses of 20% bandwidth and few GW power can be obtained

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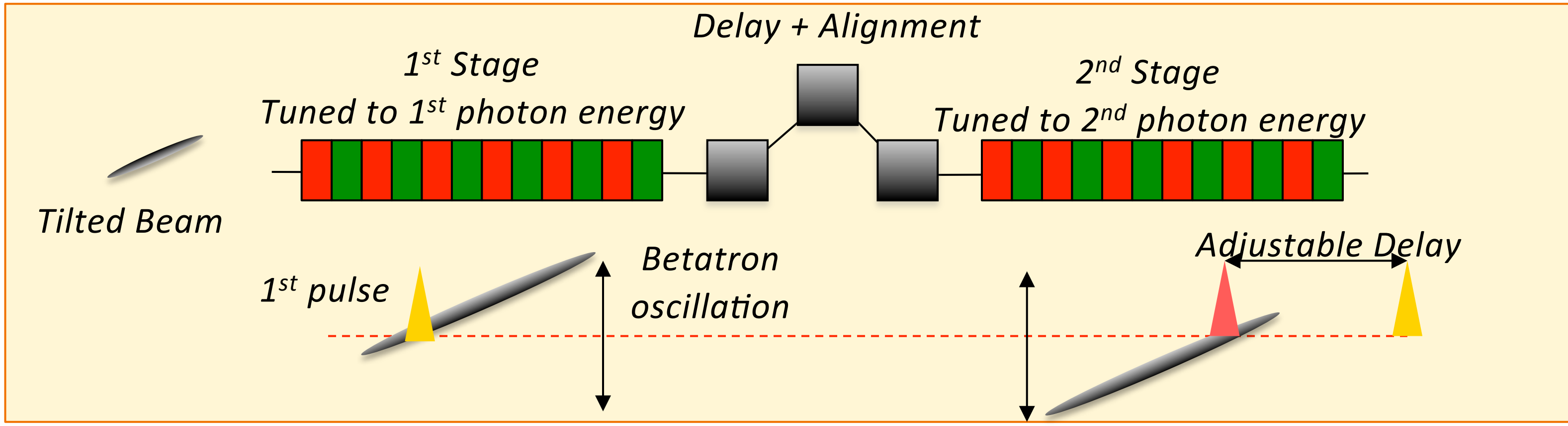
Two-color FEL pulses

In a first section the “tail” is centered and lases at λ_1. The electron beam is delayed and the “head” is realigned. In a second stage the “head” lases at λ_2.

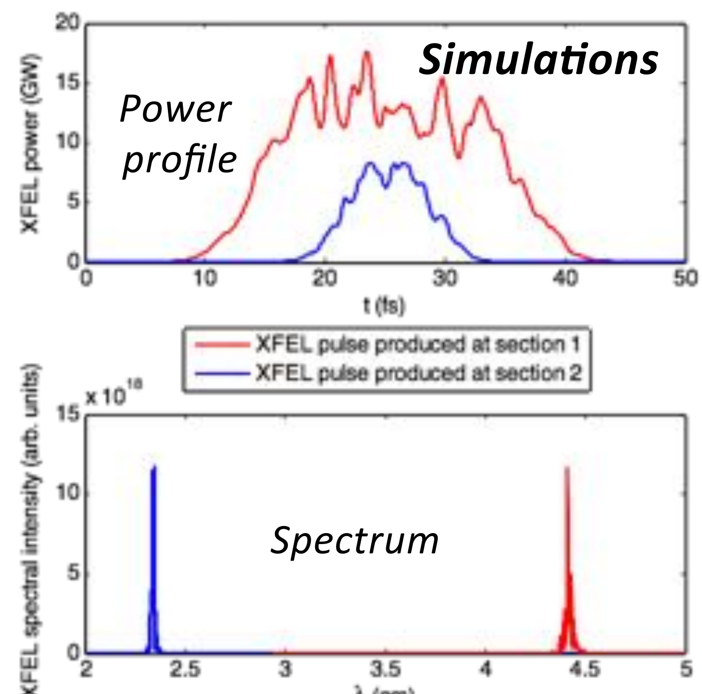


[S. Reiche and E. Prat, JSR 23, 869 (2016)]

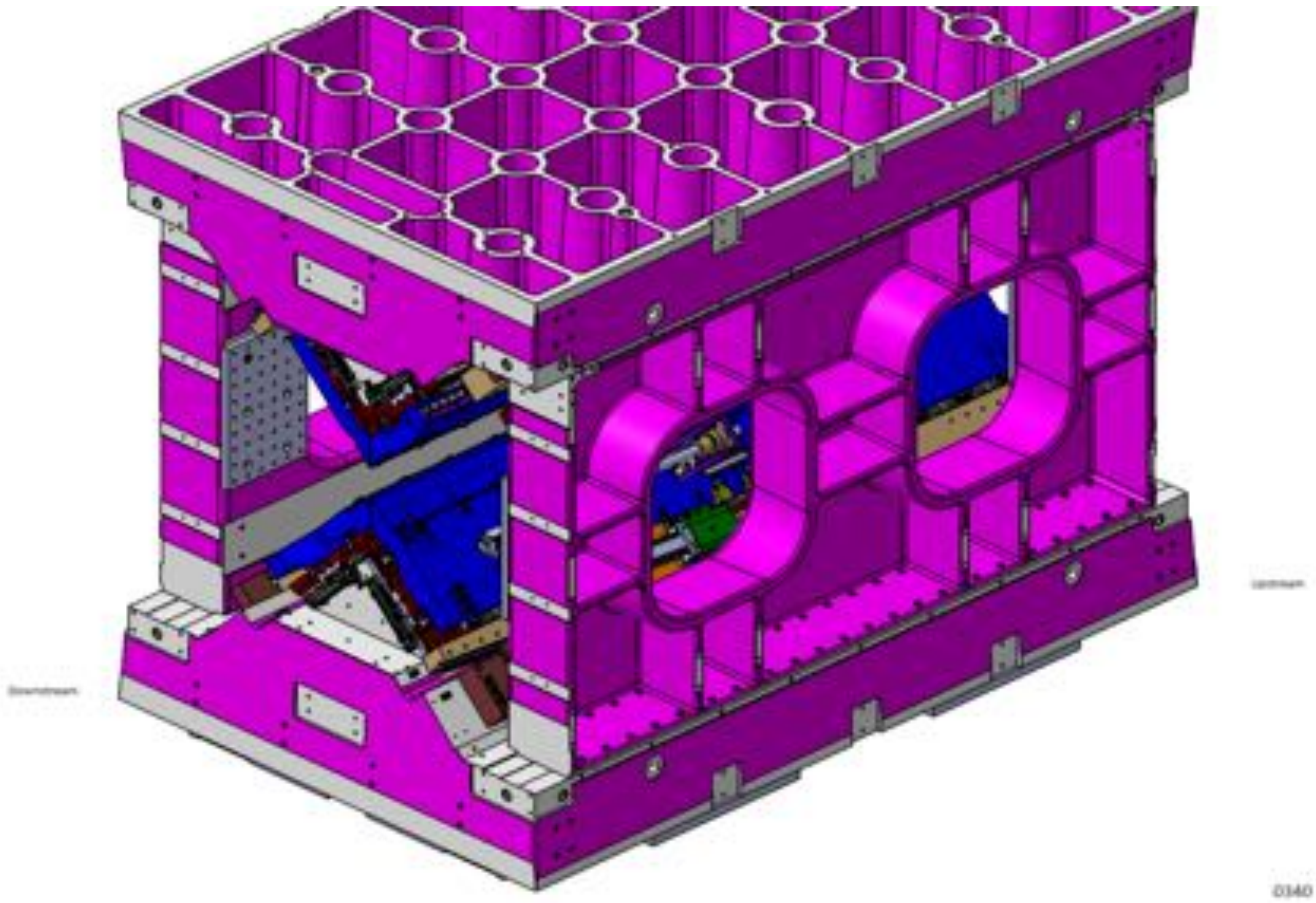
[A. Lutman et al, Nat. Photonics 10, 745 (2016)]

Tunability for Athos

Parameters	Values
Individual Pulse Length	2 – 10 fs
Individual Pulse Energy	50 – 250 µJ
Relative Delay	-10 to 1000 fs
Photon energy	Factor 5 (e.g. 240 – 1200 eV)



SwissFEL UE38 (APPLE X)



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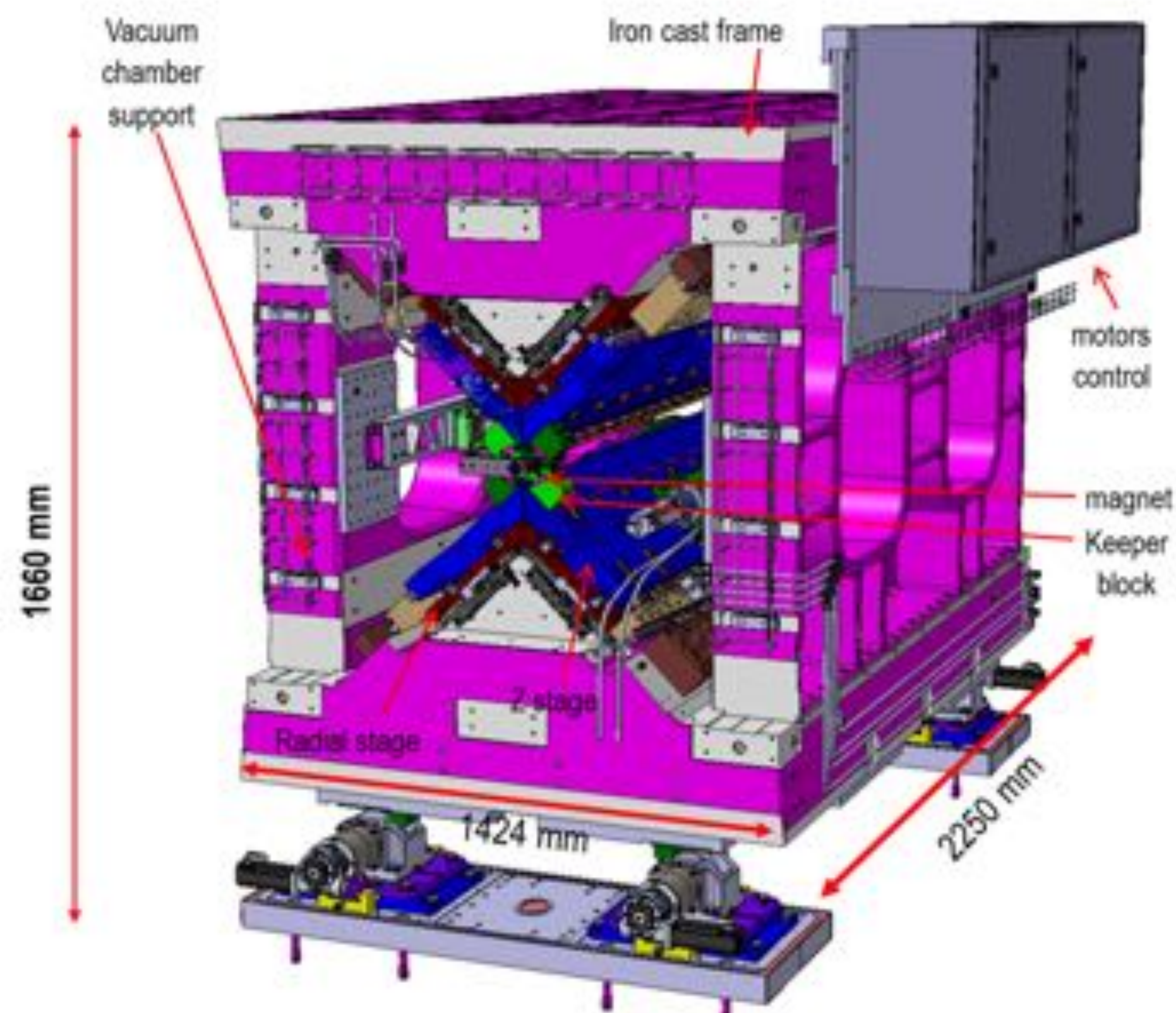
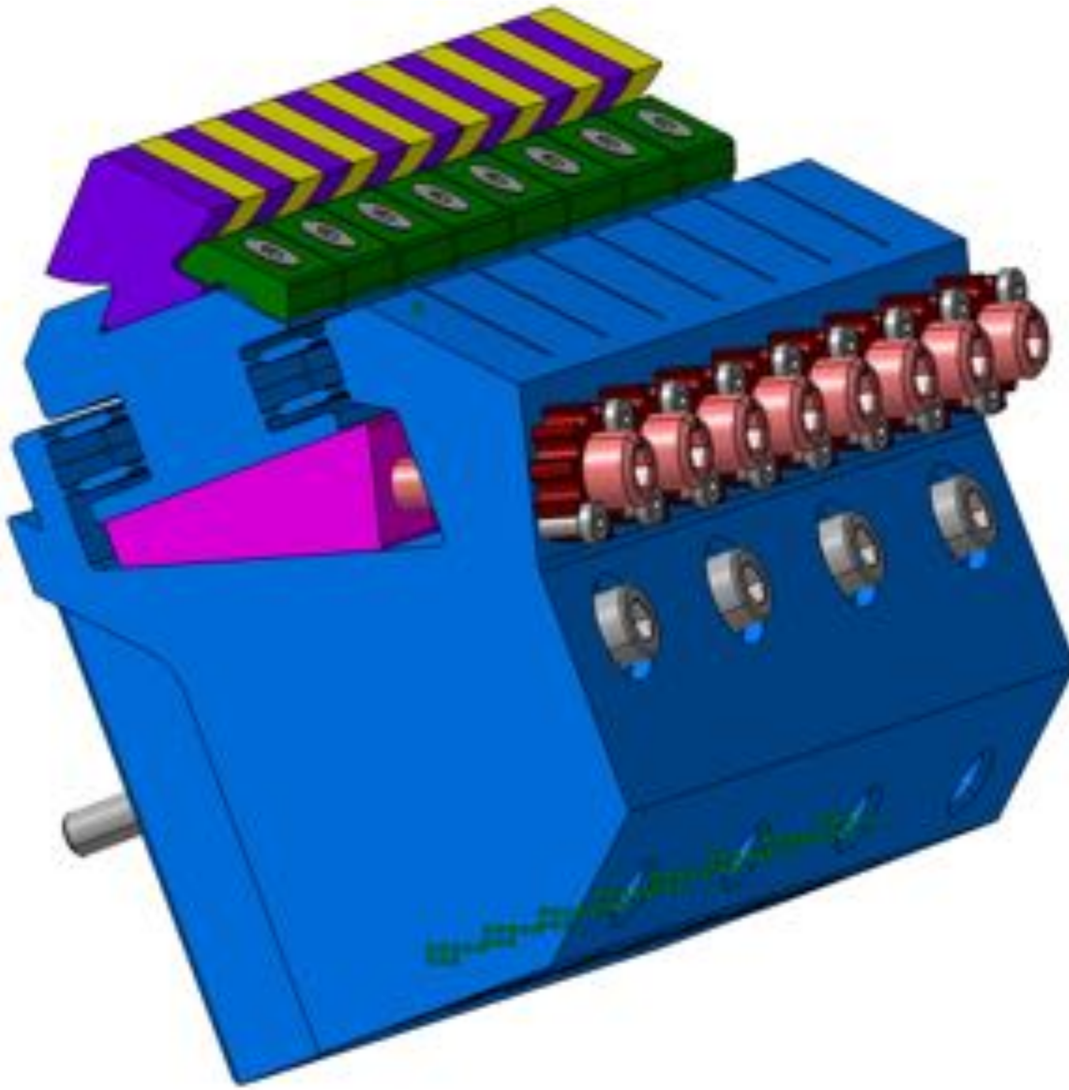


Athos undulator frame (cast iron)

Athos undulator frame (cast iron)

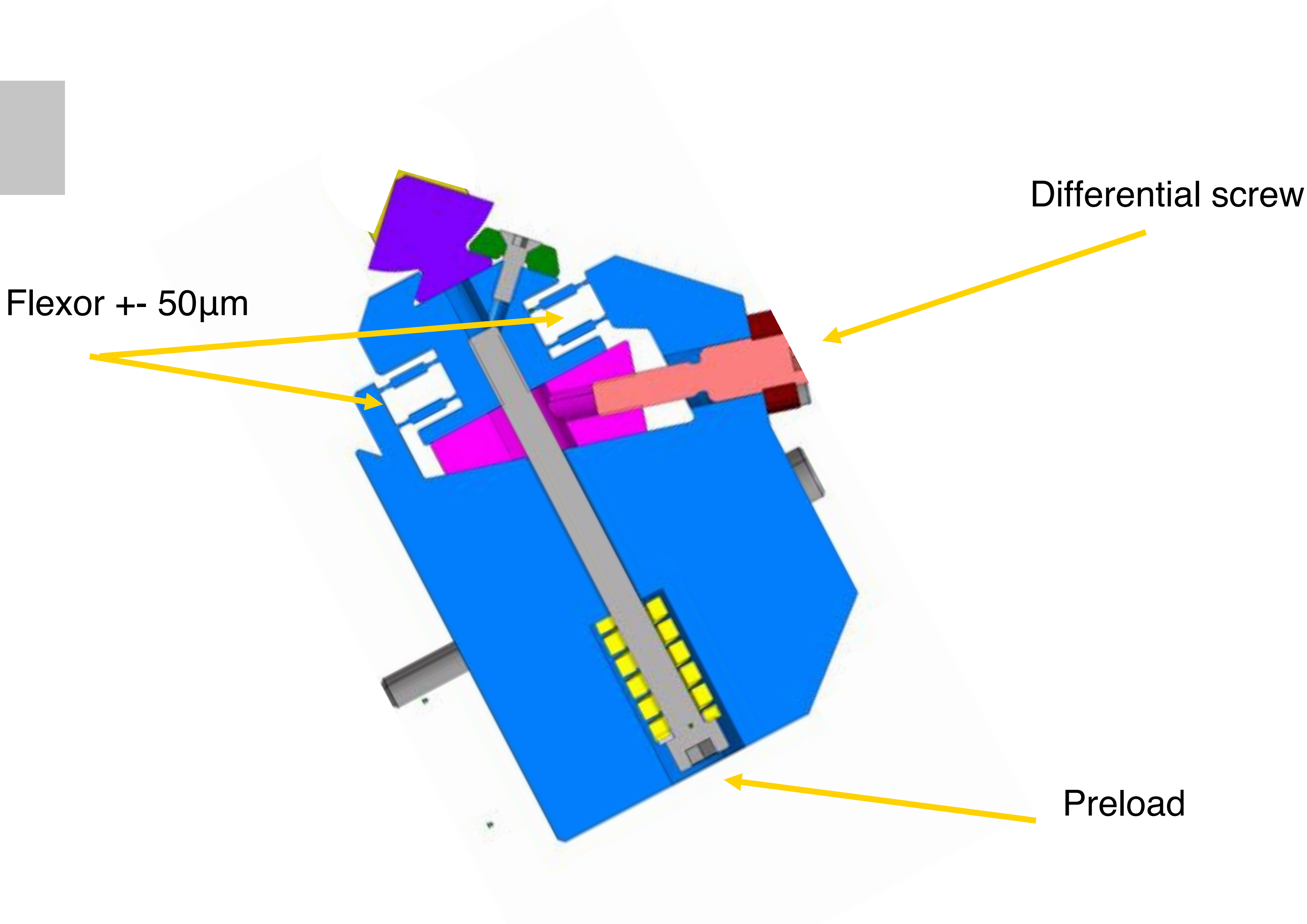
UE38 keeper block



Serial block

4 periods each

UE38 keeper block



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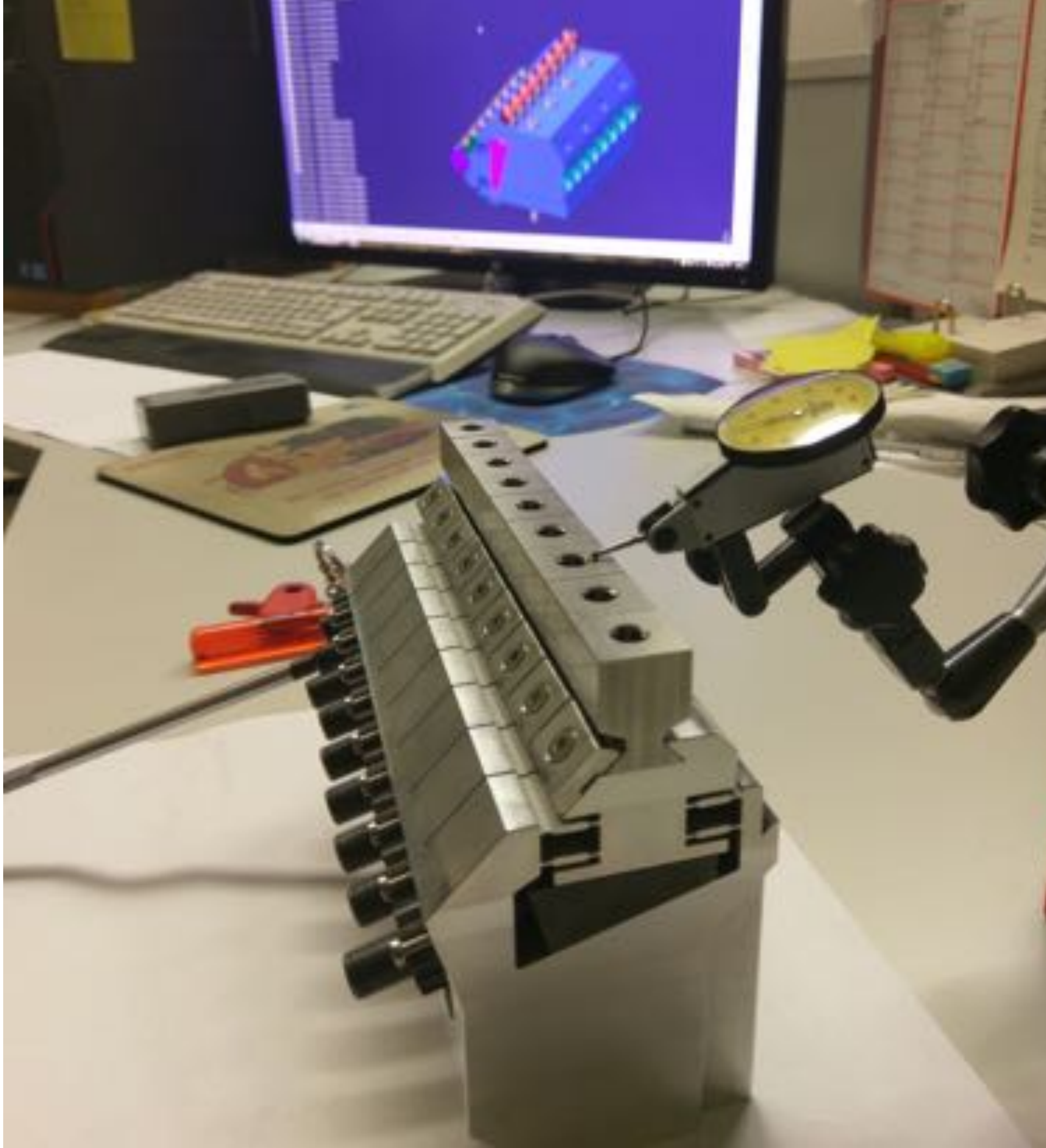
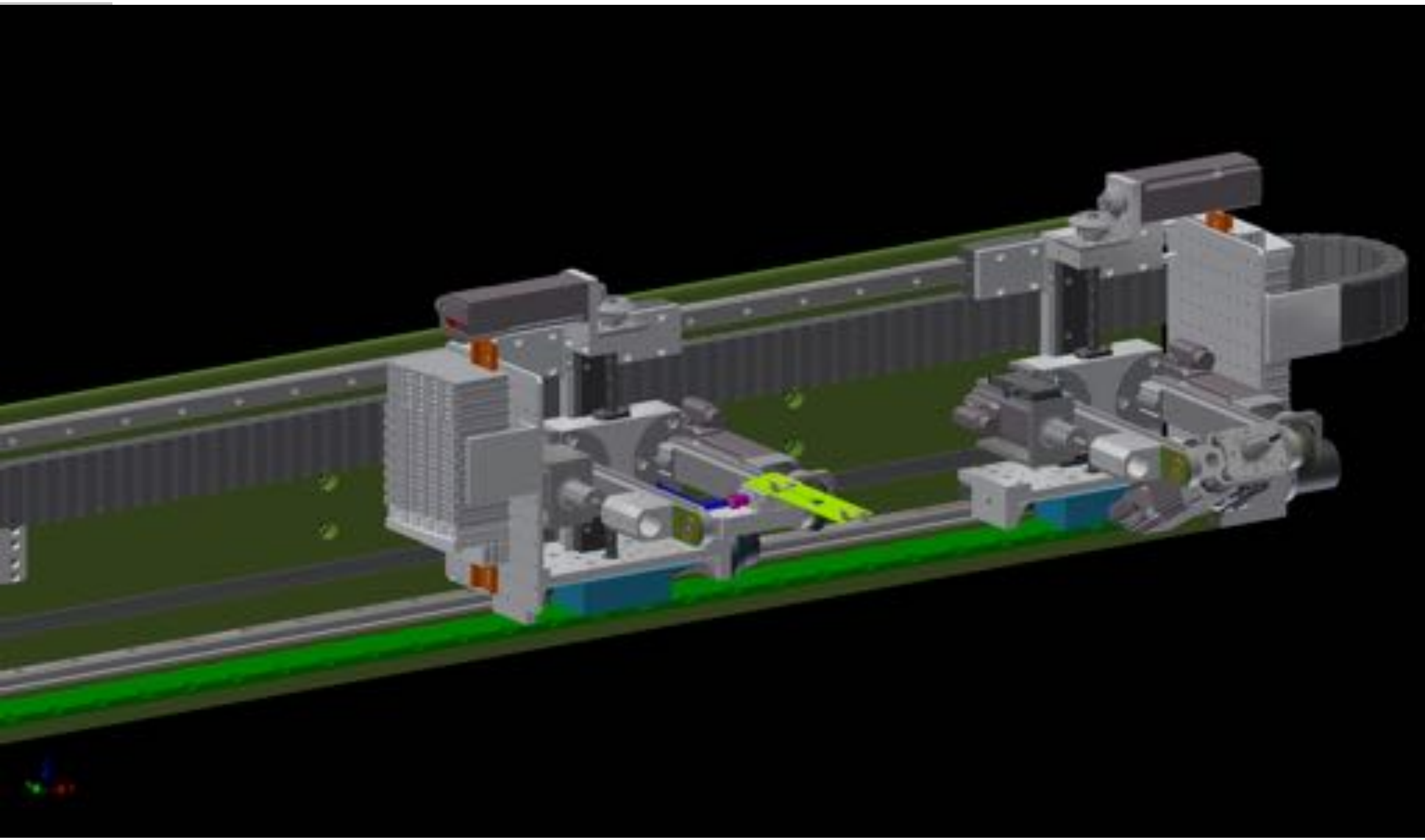
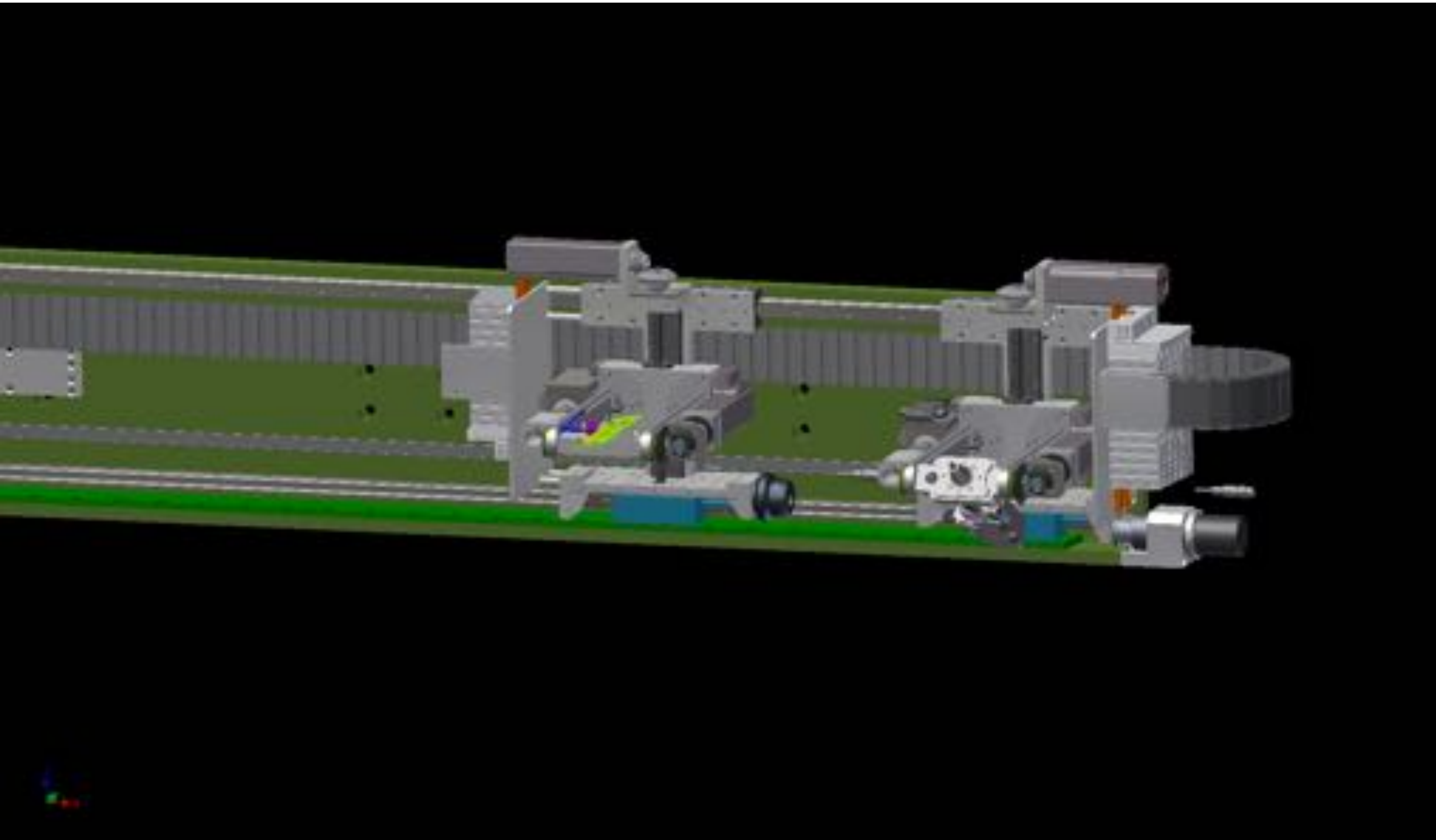


Hall probe bench with Yuri 3.0



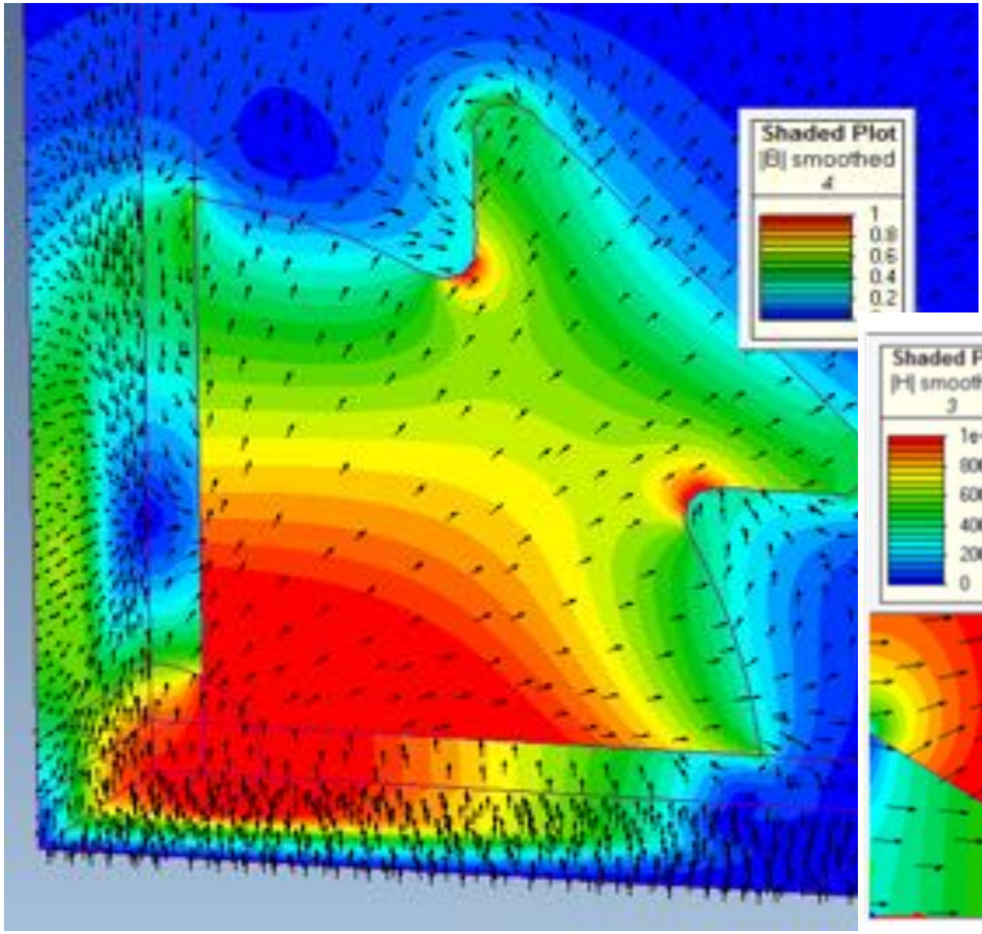
Hall probe bench with Yuri 3.0

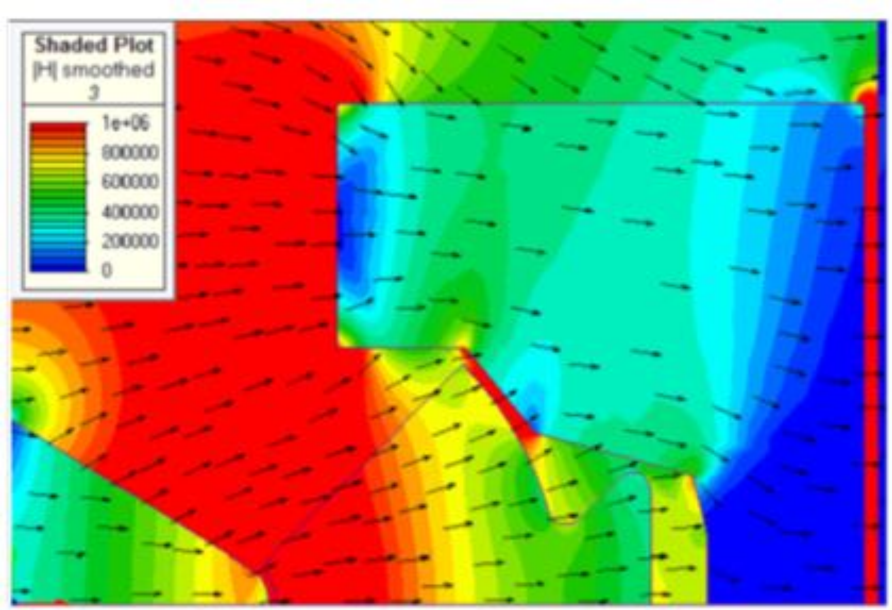


Magnets for Athos UE38

shaped field magnets: inhomogeneous magnetization

performance study[1] with Arnold Magnetics, Lupfig AG, Switzerland under way





use of SmCo magnets

- temperature stability
- nonlinearities

UE38 magnet material options

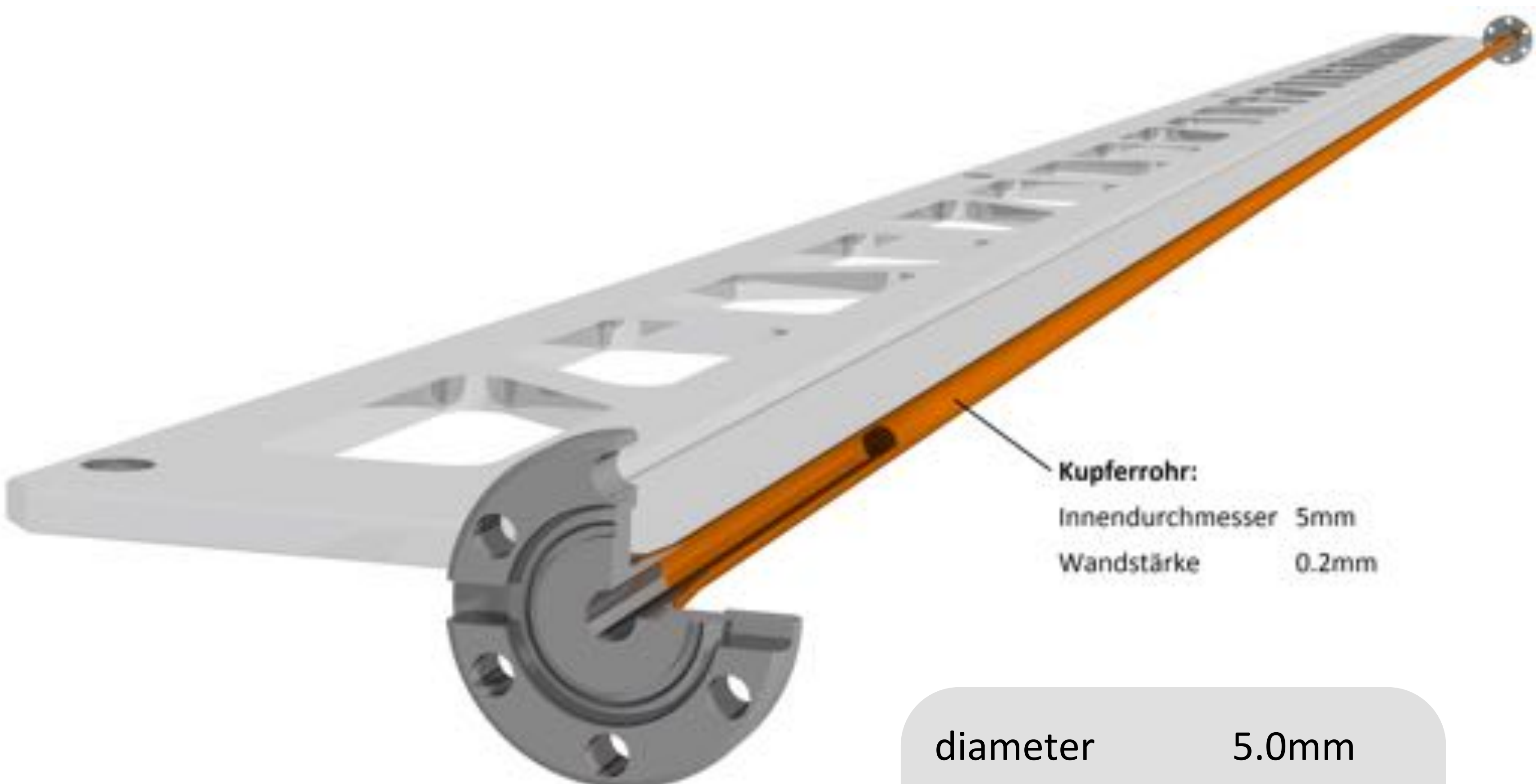
Magnet A	Magnet B	shaped field	K	Photon Energie [eV] @ 2.65 GeV	Photon Energie [eV] @ 2.9 GeV	in Specs @ 2.65 / 2.9 GeV
$SmCo_5$	$SmCo_5$	nein	3.42	256	306	ja / nein
$SmCo_5$	$SmCo_5$	ja	3.57	238	285	ja / nein
$SmCo_5$	Sm_2Co_{17}	nein	3.74	220	263	ja / nein
$SmCo_5$	Sm_2Co_{17}	ja	3.9	203	243	ja / ja
Sm_2Co_{17}	Sm_2Co_{17}	nein	3.95	199	238	ja / ja
Sm_2Co_{17}	Sm_2Co_{17}	ja	4.11	185	222	ja / ja

axial magnet A responsible for shift dependent kicks

better performance of $SmCo_5$

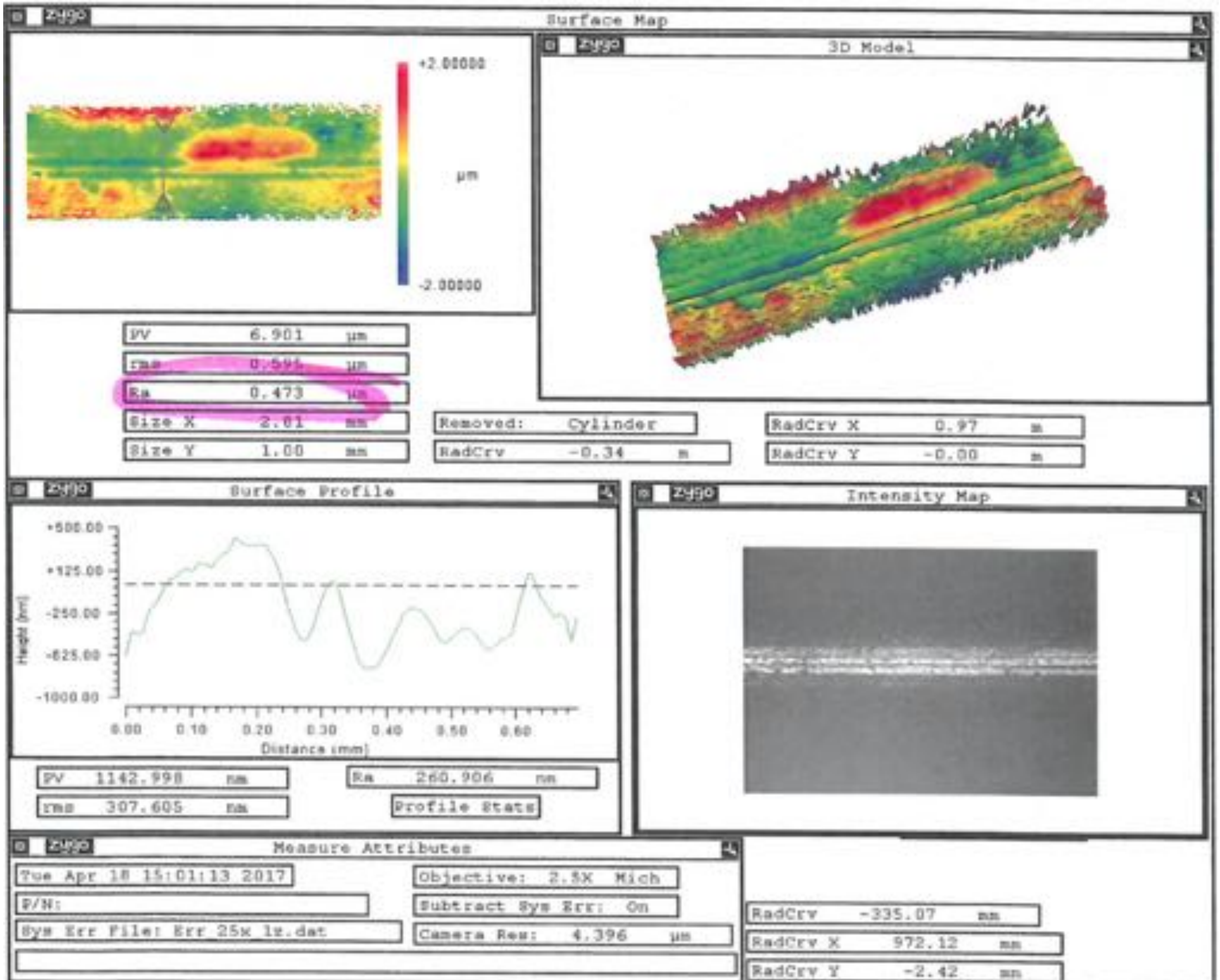
Sm_2Co_{17} better suited for use in shaped field because of less anisotropy

Ultra-thin Vacuum chamber for UE38

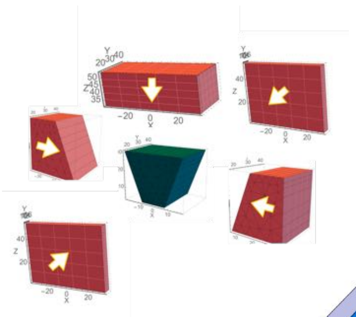


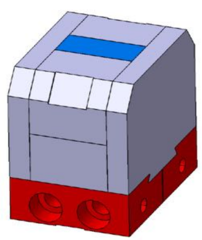
Cu chamber
galvanic on silicon hose
round or elliptical up to 2:1

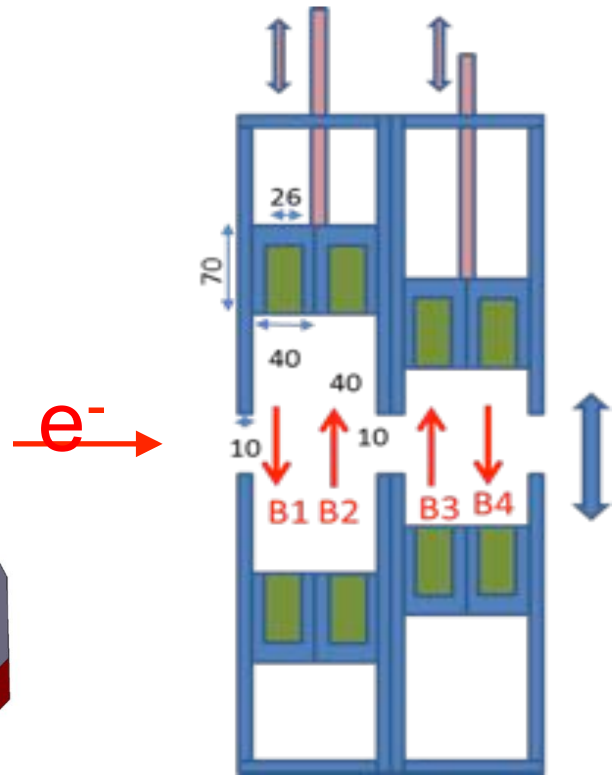
diameter	5.0mm
wall thickness	0.2mm
magnet aperture	6.5mm
minimum gap	3.0mm

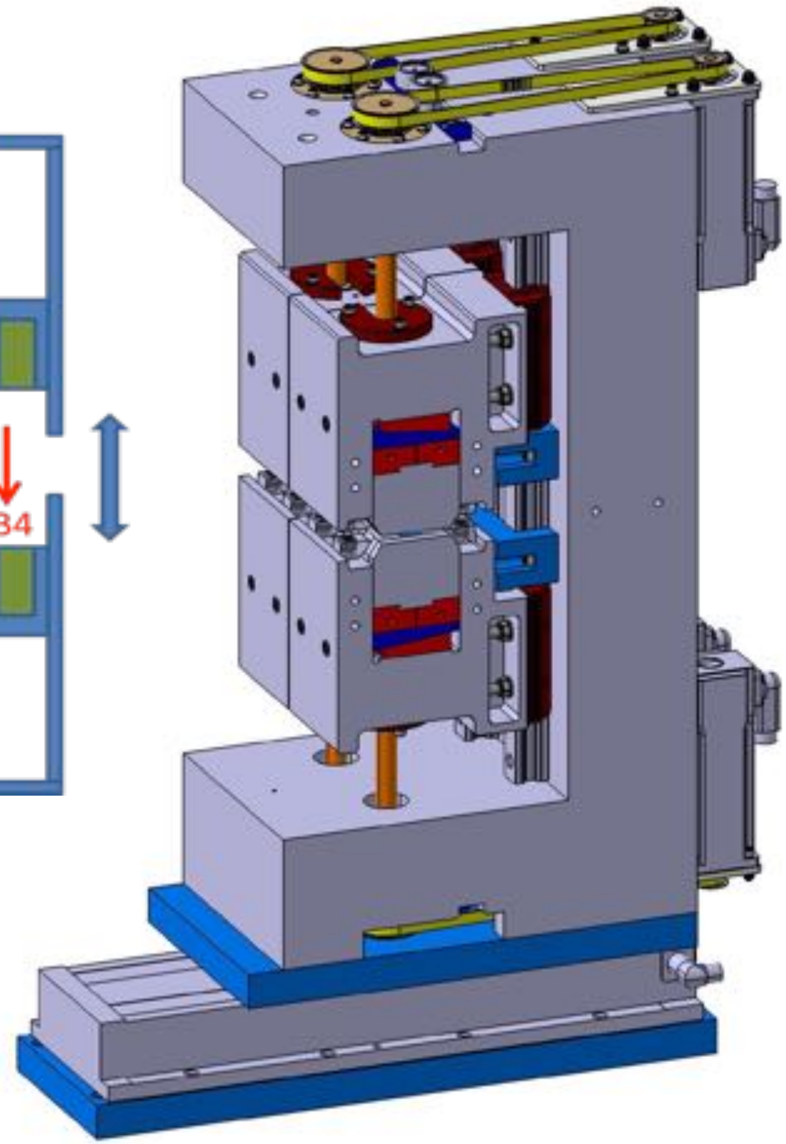

Surface Map
3D Model
+2.00000
µm
-2.00000
PV 6.901 µm
rms 0.595 µm
Ra 0.473 µm
Size X 2.81 mm
Size Y 1.00 mm
Removed: Cylinder
RadCrv -0.34 m
RadCrv X 0.97 m
RadCrv Y -0.00 m
Surface Profile
+500.00
+125.00
-250.00
-625.00
-1000.00
Height (nm)
0.00 0.10 0.20 0.30 0.40 0.50 0.60
Distance (mm)
PV 1142.998 nm
rms 307.605 nm
Ra 260.906 nm
Profile Stats
Intensity Map
Measure Attributes
Tue Apr 18 15:01:13 2017
P/N:
Sys Err File: Err_25x_lz.dat
Objective: 2.5X Mich
Subtract Sys Err: On
Camera Res: 4.396 µm
RadCrv -335.07 mm
RadCrv X 972.12 mm
RadCrv Y -2.42 mm

Chicane





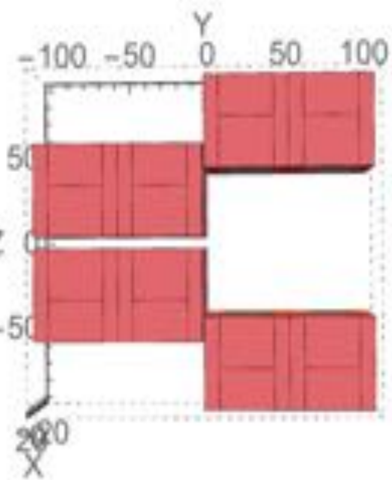


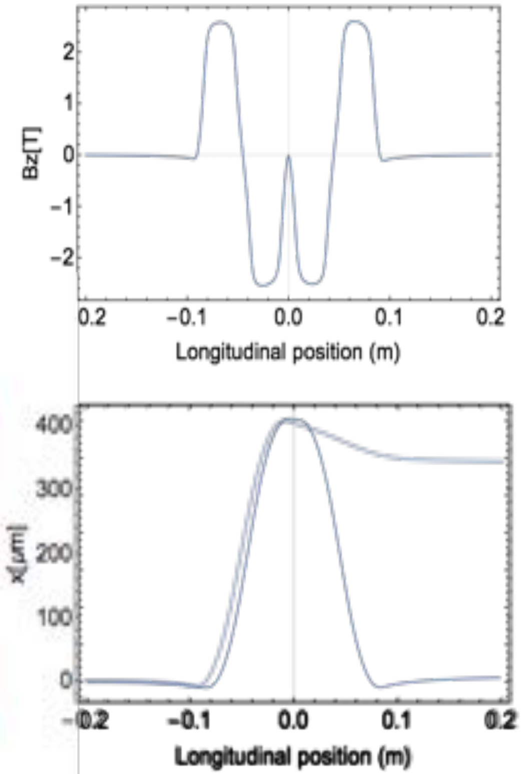


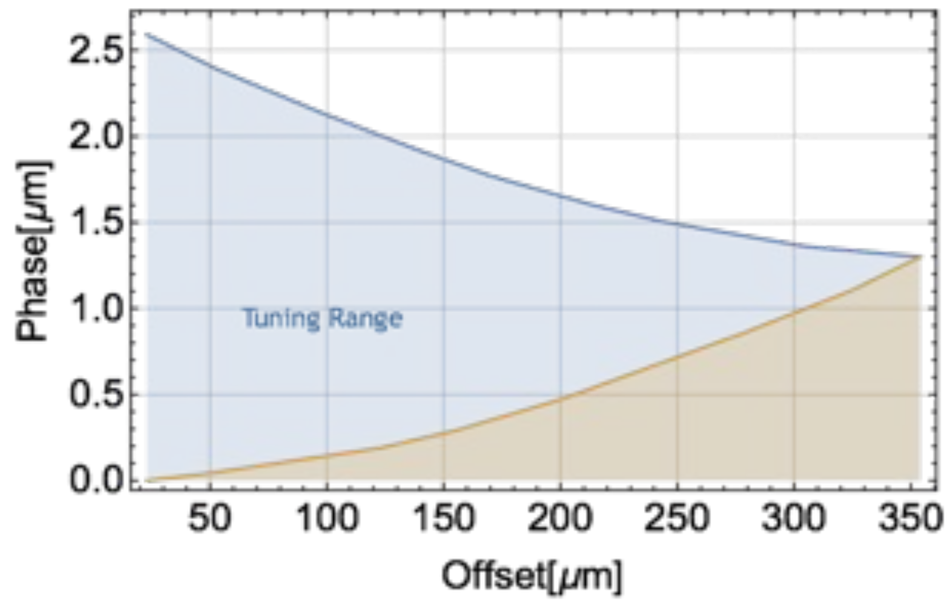
4 motors for various modes:

- Chicane
- Offset
- Phase Matching

Athos Phase Matcher / Chicane







Chicane mode:

200µm offset and 1.5µm phase advance

Phase matcher mode:

at 80mm gap

SwissFEL & SLS-2: concept

SLS 2.0 2.4 GeV

soft x-ray variable polarization

APPLE II / APPLE X

gap min = 4mm, 2m long

hard x-ray

in - vacuum

U19 -> CPMU14 / 12

U10 sc ?!

gap min = 4mm, 2m long

2.9 - 3.4 GeV SwissFEL 2 - 8 GeV

soft x-ray variable polarization

APPLE-X (DELTA II)

UE38, Chic Modes

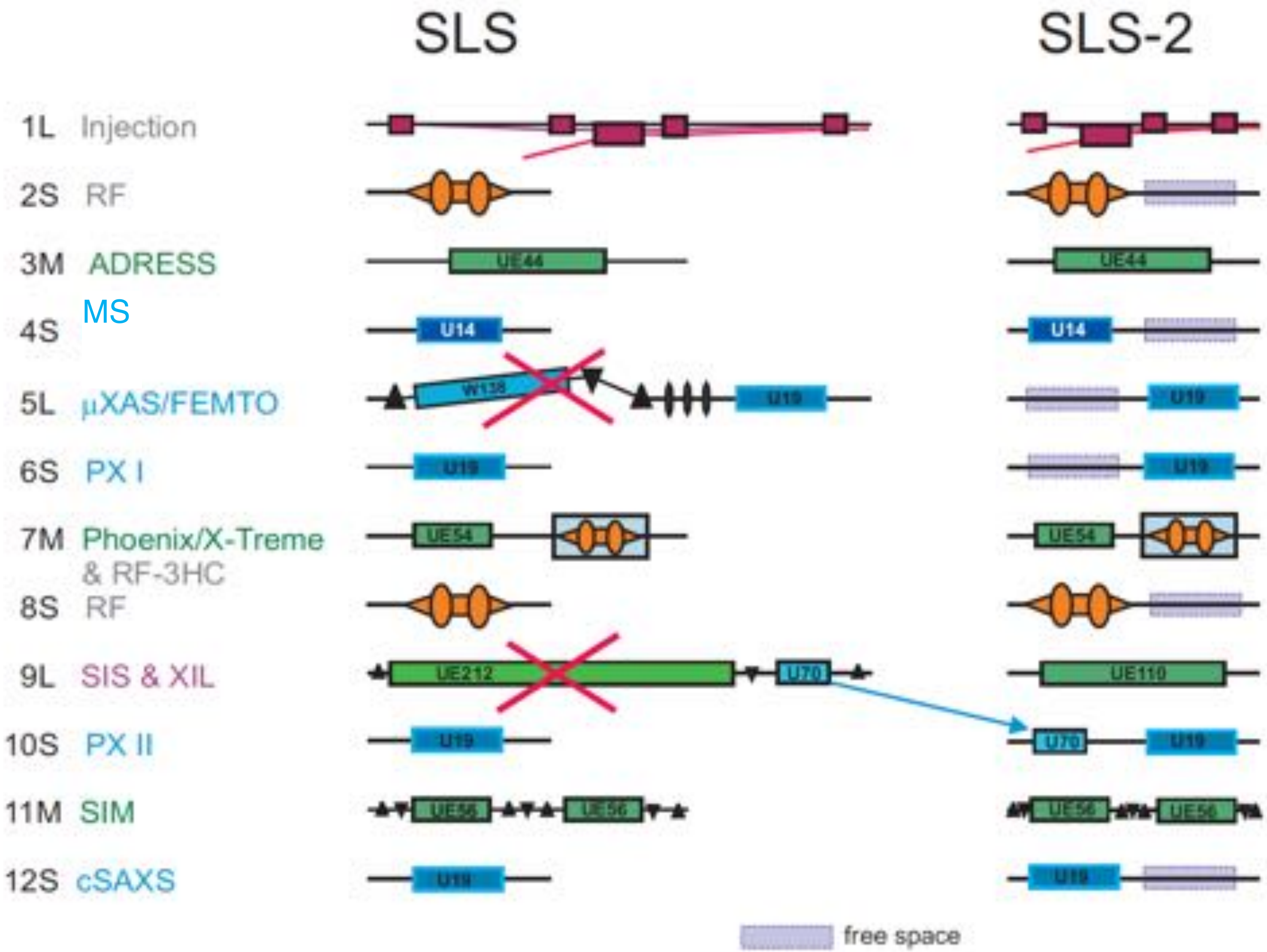
in - vacuum

U15 3mm, 4m long -> 12keV

U10 sc ?! (2025 ff) -> 36keV

SLS-2 beamline options - I

courtesy Andreas Streun

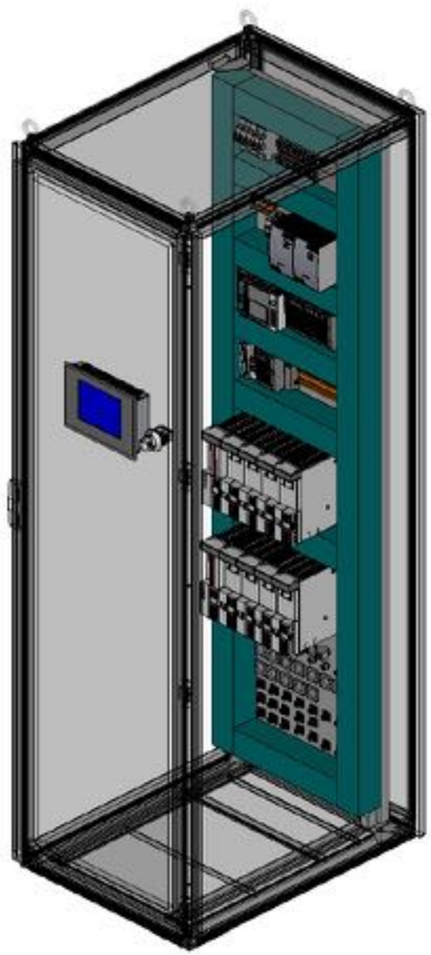


SLS-2 beamline options - II

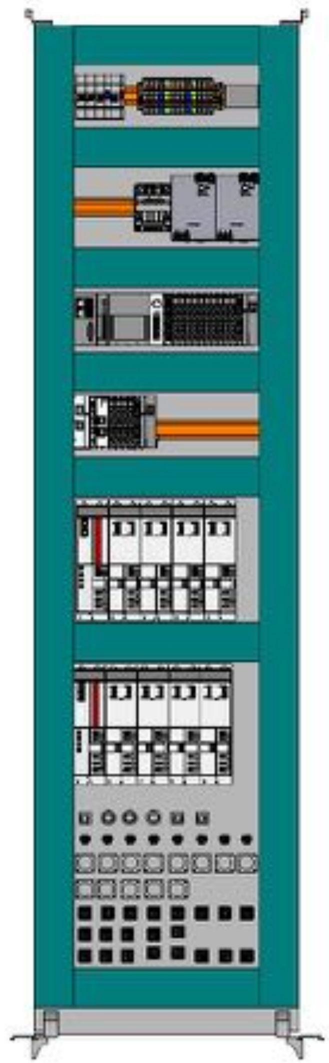
1	Injection				free exp area
2	RF	EEHG			free exp area
3	EEHG	UE38		ADRESS	coherent radiation
4		U14		MS	
5	U60	U14	XIL	µXAS	XIL use of 1 UE56?
6		U14		PX I	
7	UE54	UE50	Phoenix	X-Treme	
8	RF	3HC			entrance
9		U14		cSAXS	
10		U14		PX II	
11	UE56	UE56	SIM		
12	UE90	UE90	SIS		

4 free slots

SLS-2 Undulator Control



APPLE X motor control



SLS: VME / OMS motor control

+ Siemens S5 PLC

Design < 2000 (2 cabinets per ID)

SwissFEL: Beckhoff Motion Control

combines

motor control

safety

compact, low price

fast Ethercat connection

cabinets on board

SLS-2: will adapt SwissFEL design

external cabinets: 1 per ID

one design for all types

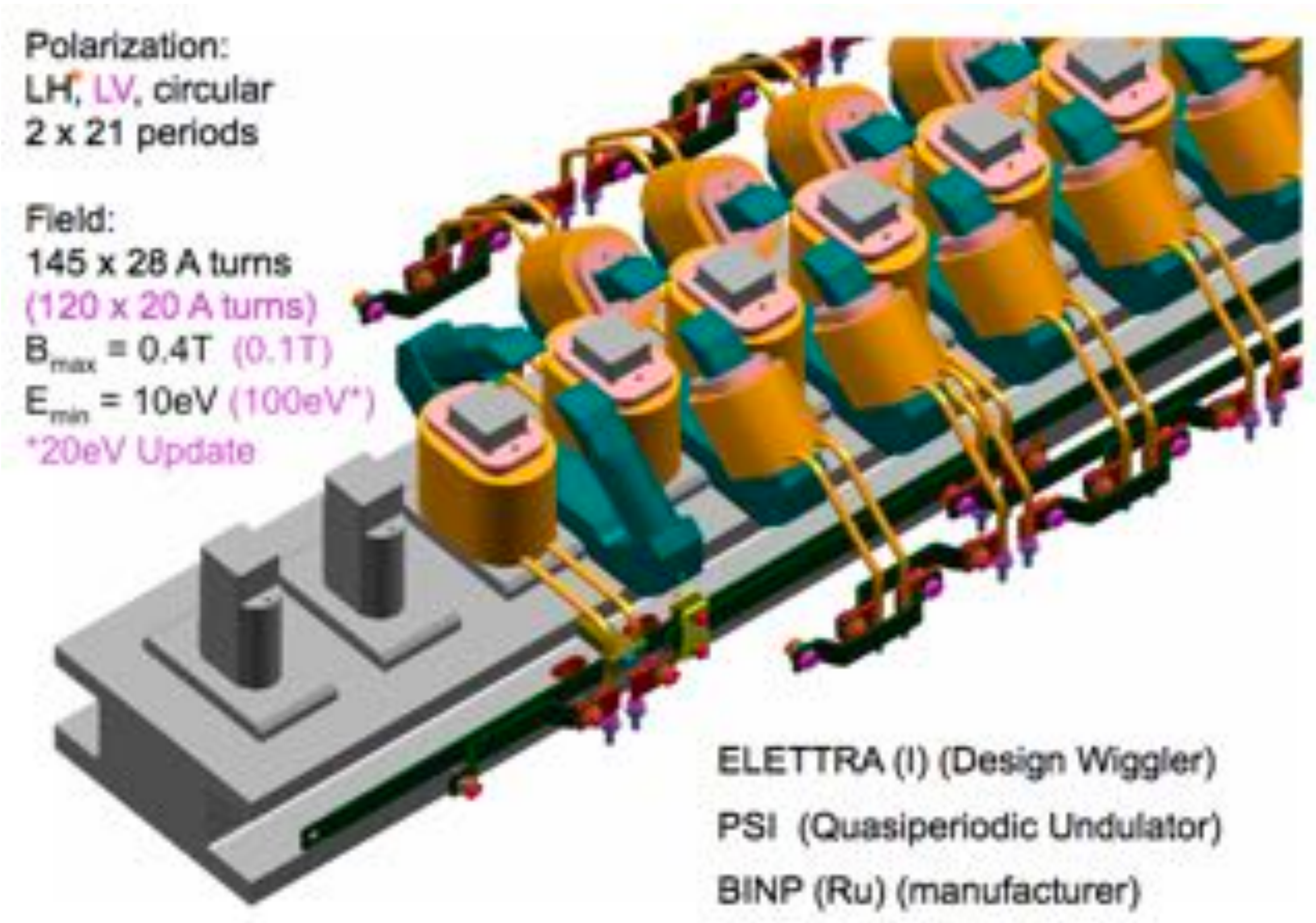
APPLE X ist most complex

PAUL SCHERRER INSTITUT

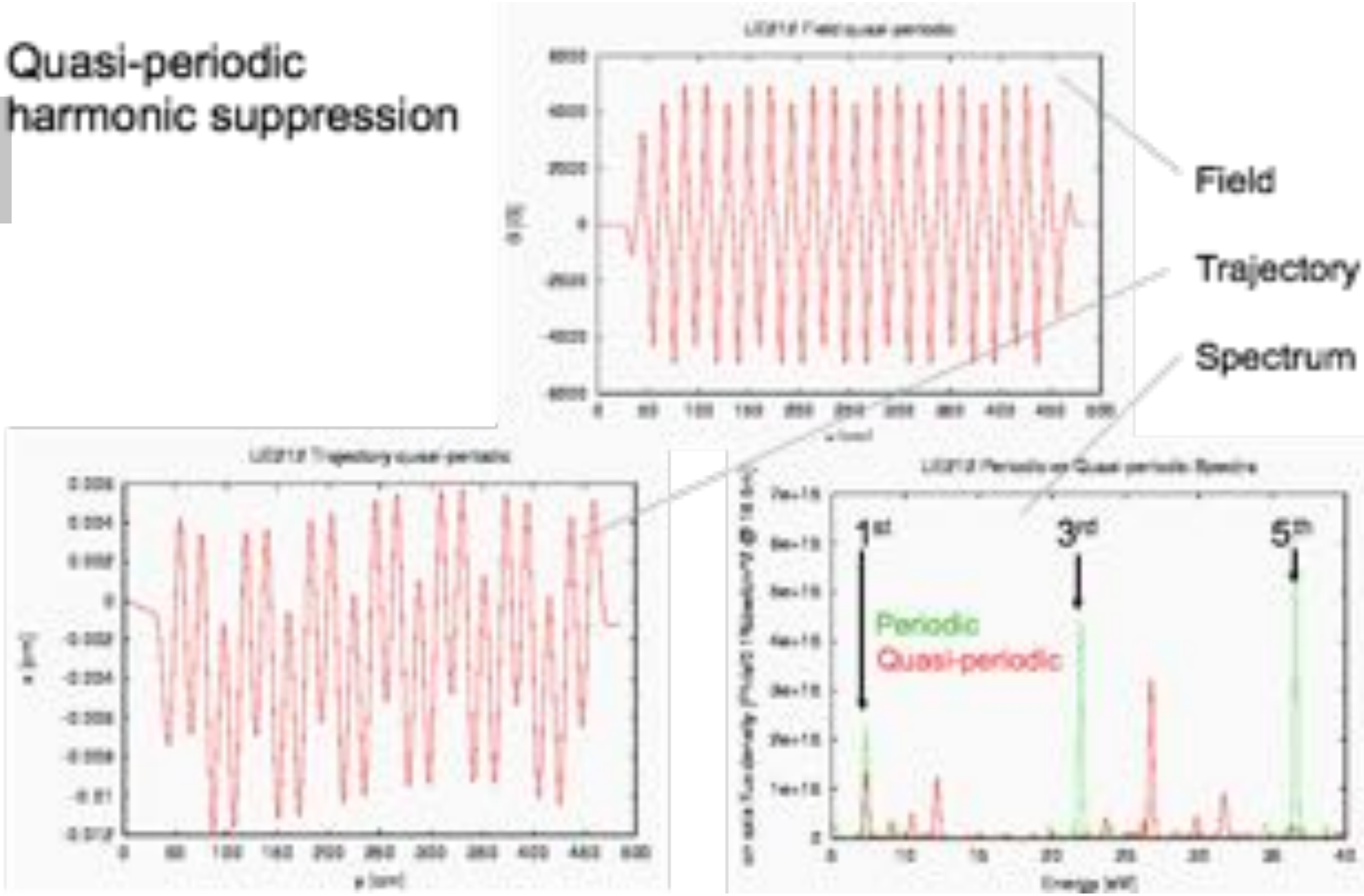
SIS Undulator UE212/424

PAUL SCHERRER INSTITUT

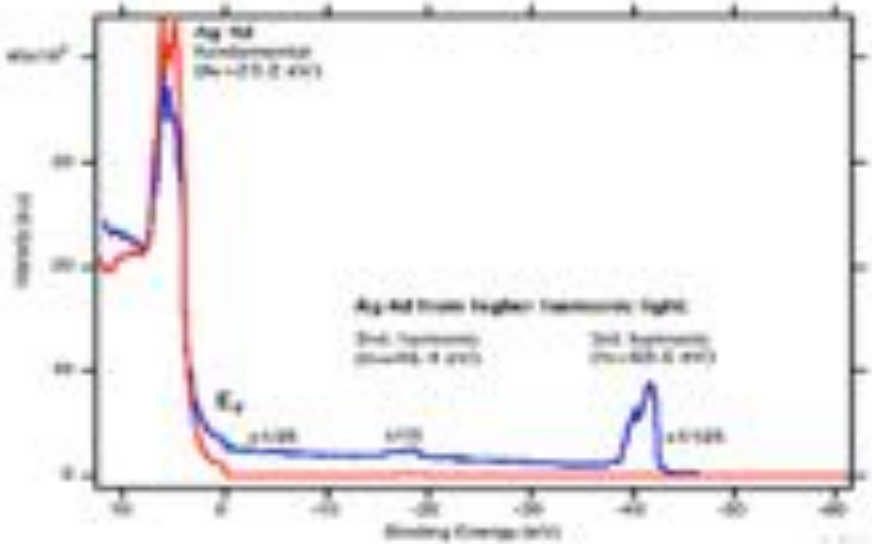
UE212 quasi-periodic electromagnetic

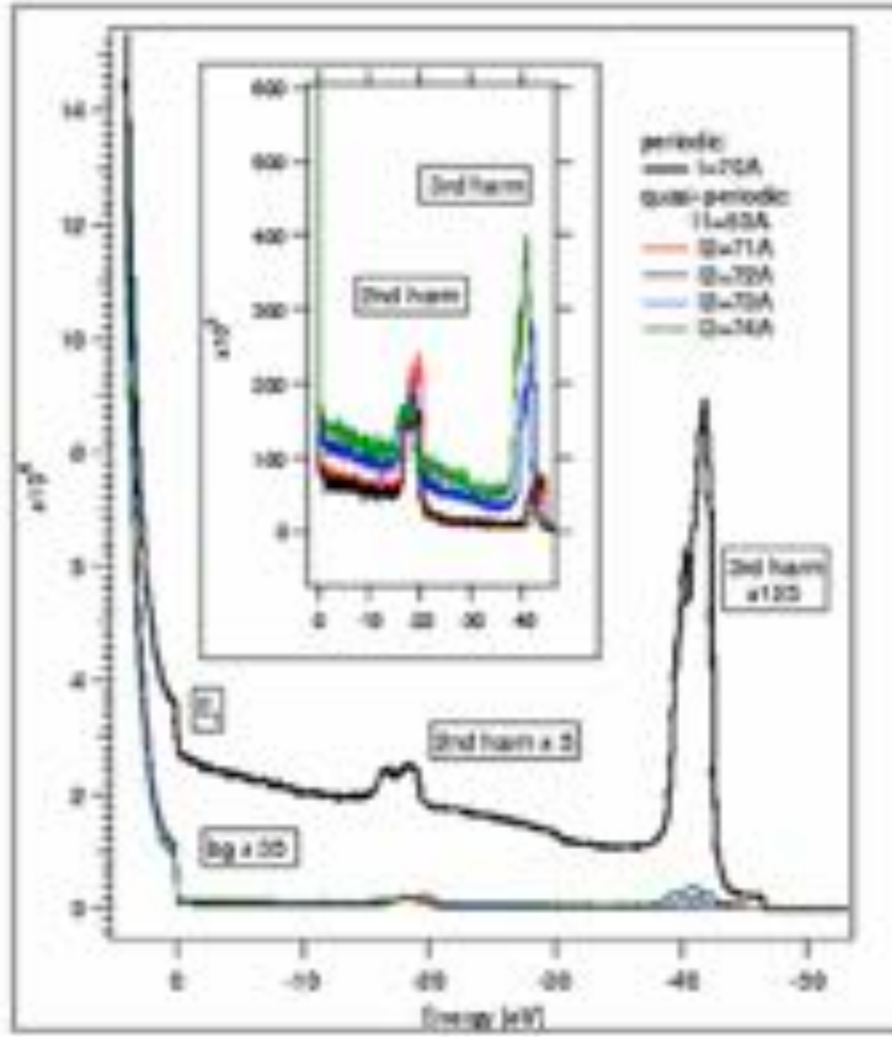


Quasi-periodic harmonic suppression



Harmonic suppression in Photoemission Spectra

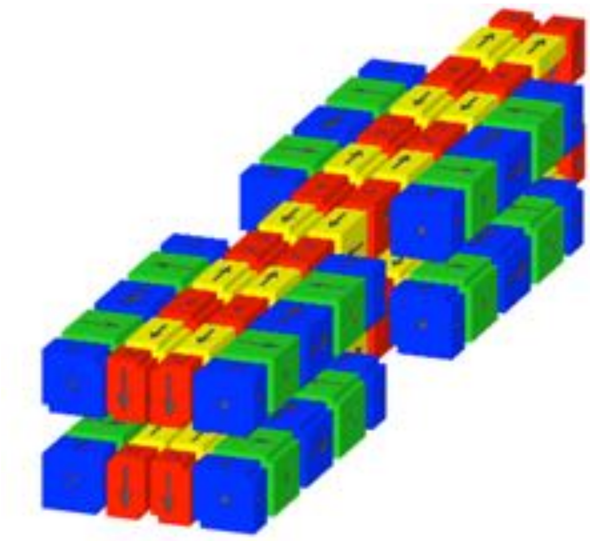




Optimization by

- Amplitude variation (ID)
- PGM (20 – 800 eV) or
  NIM (8 – 30 eV) monochromator

SIS: replacement of the elm qp undulator UE212



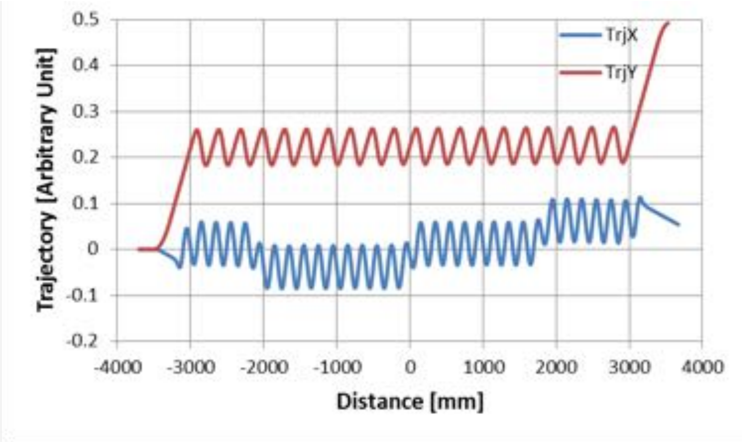
QUASI-PERIODIC KNOT-APPLE UNDULATOR

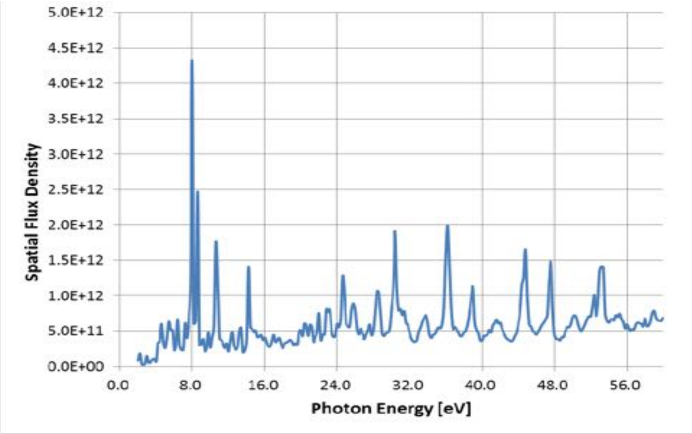
LH, LV, circular without on axis power
quasi-pedicic field distribution

drawback: only fundamental

with K = 0.5	U80	613eV
	U90	545eV
	U100	490eV

pretty complicated





S. Sasaki et al, POSSIBILITY FOR QUASI-PERIODIC KNOT-APPLE UNDULATOR, 2014

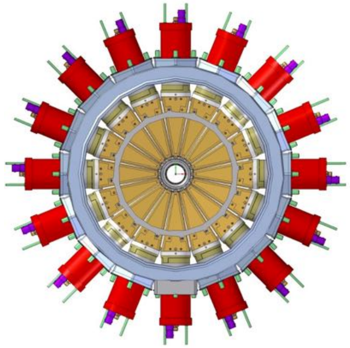
first device under construction for SSRF

Workshop on IDs for 4GLS (Berkeley 2017):

Quasiperidic APPLE devices are too much compromise

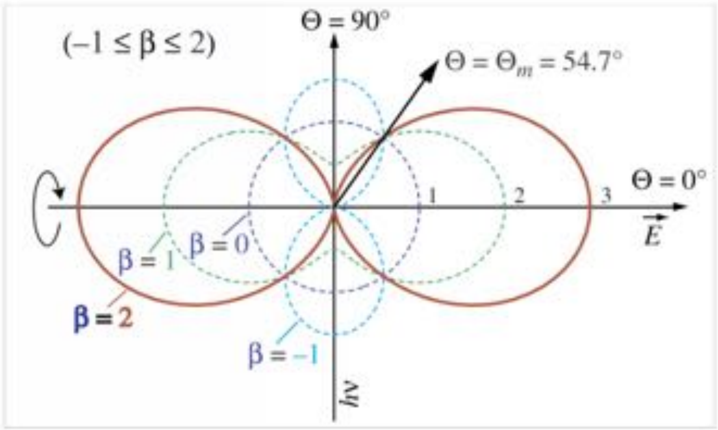
twin APPLE undulators

Single Shot Polarimeter



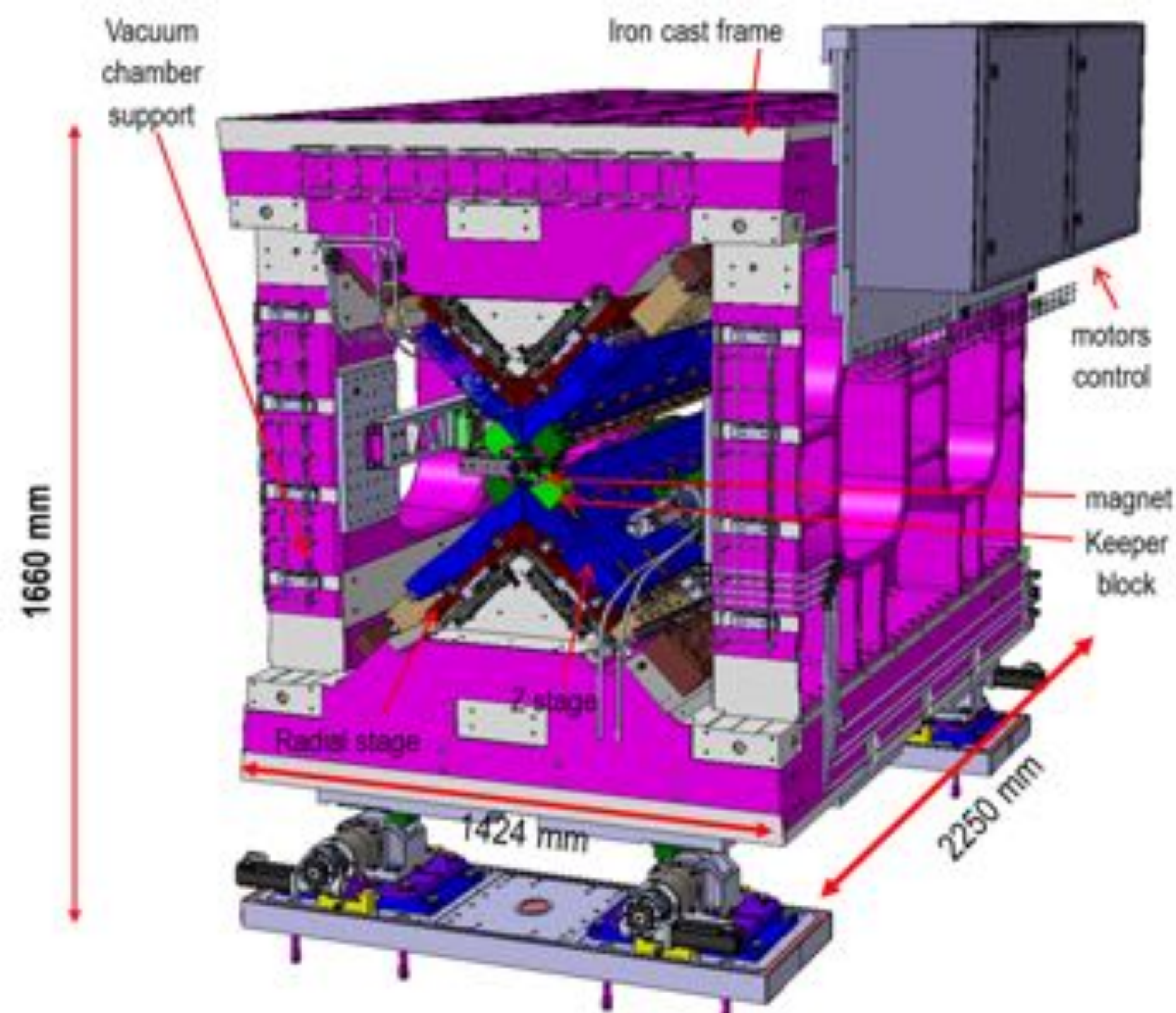
LH, LV out of circular light
no harmonics, no power on axis
standard operation for higher energies
use of harmonics possible
range 10 (15) eV – 600 (1000) eV

polarization control with single shot polarimeter

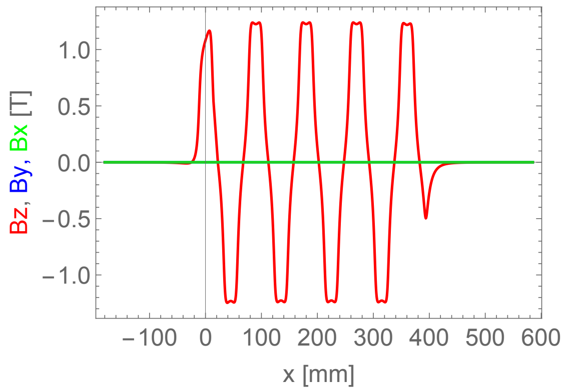


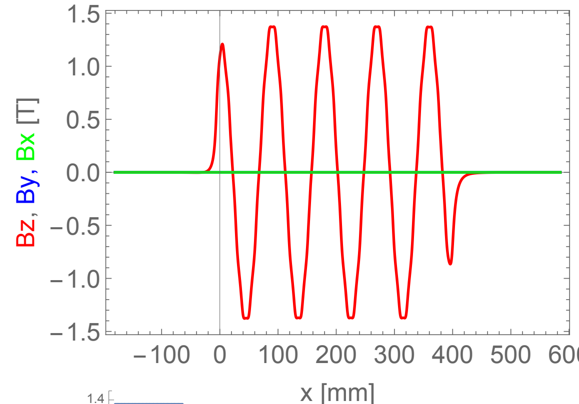
courtesy Jens Viefhaus (DESY)

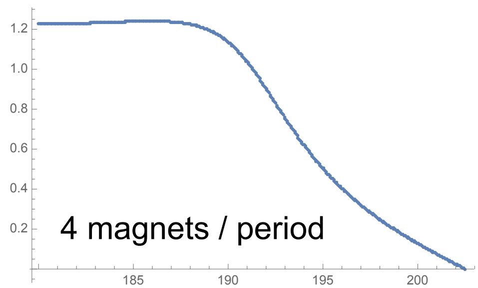
SwissFEL UE38 prototype

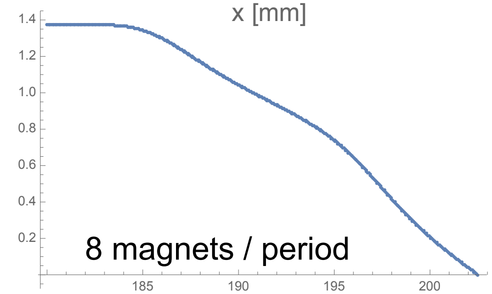


SLS-2 UE90 design study







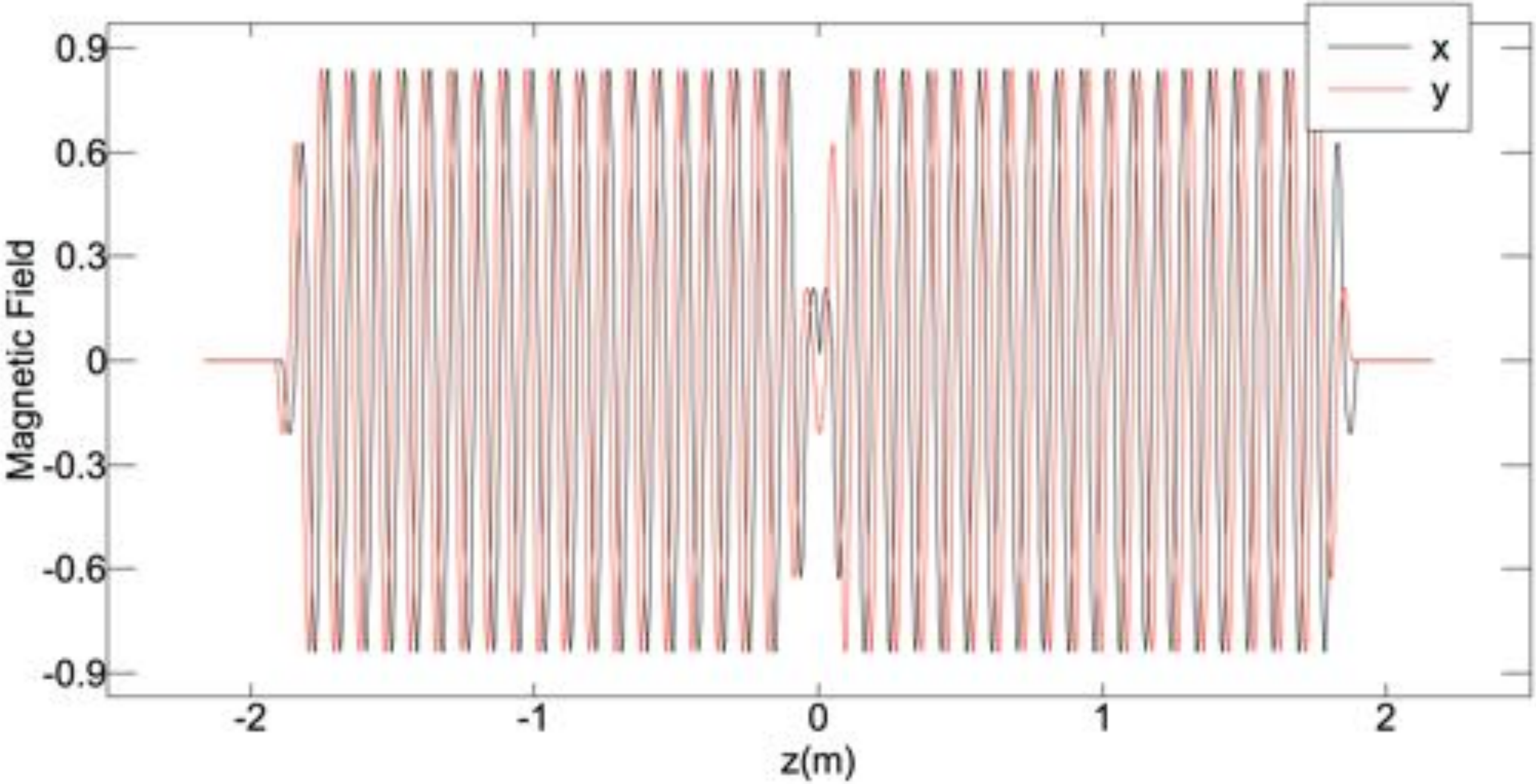


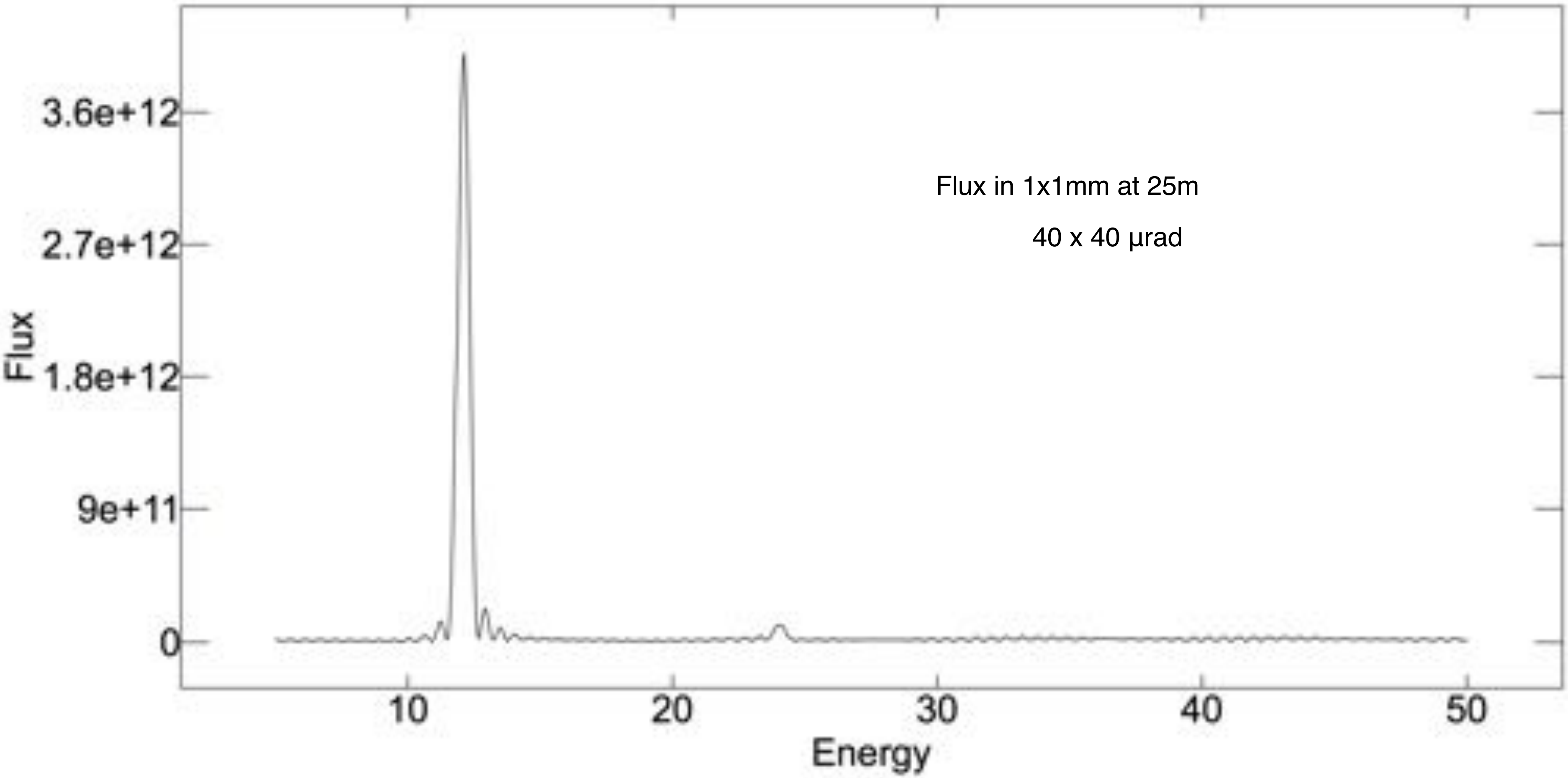
UE90	Beff [T]	Keff	Energy [eV]
4 magnets / period	1.10	9.24	14.02
8 magnets / period	1.187	9.98	12.07

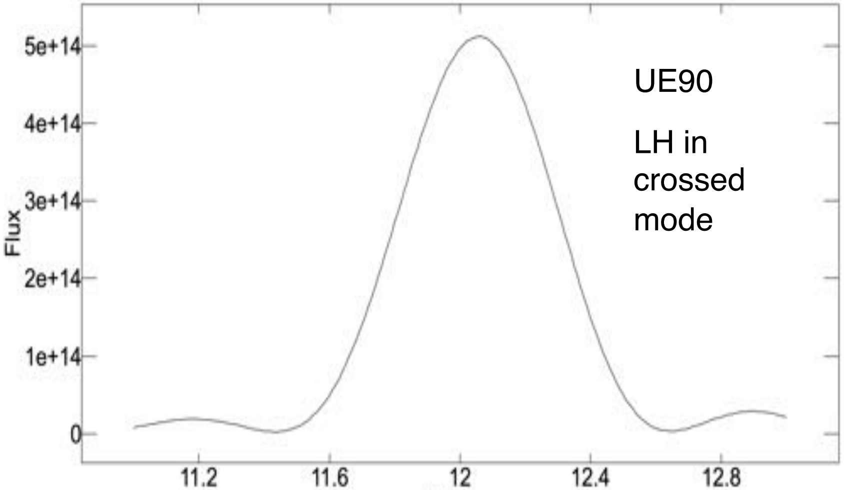
Field enhancement: 8%

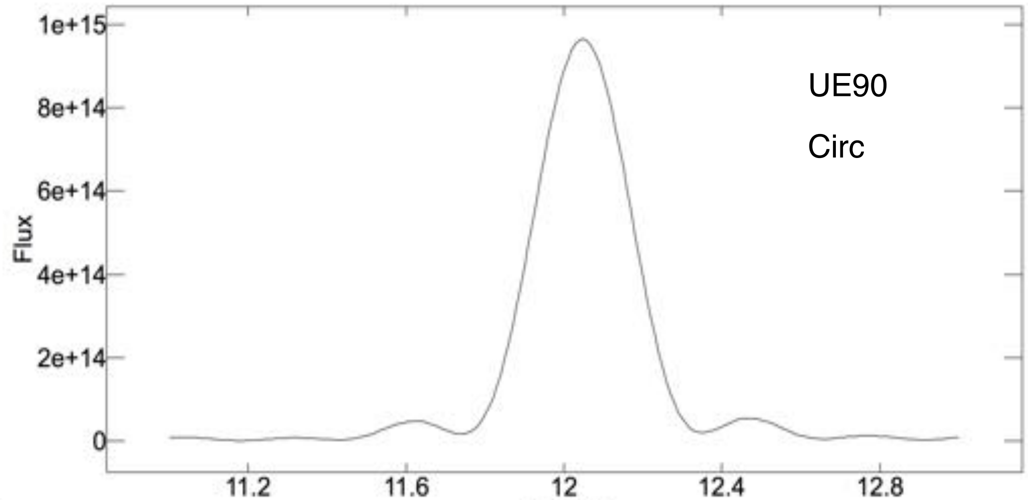
Note: PSI builds 4 UE90 of APPLE X type for EUXFEL

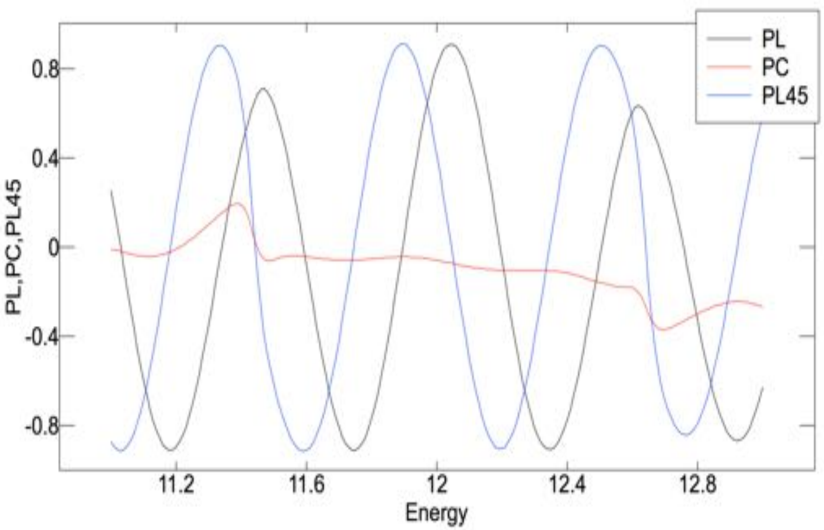
UE90 2x1.9m 2x19 periods

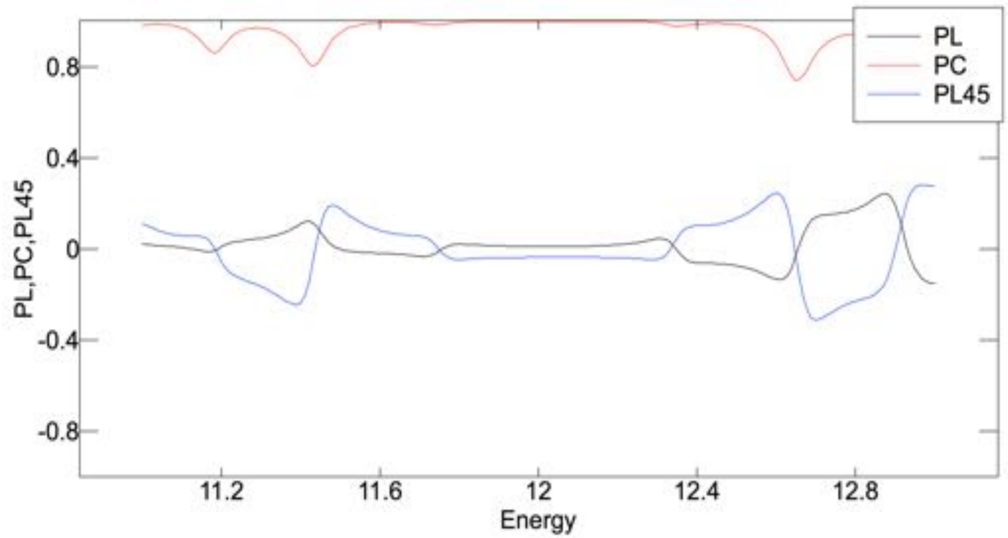


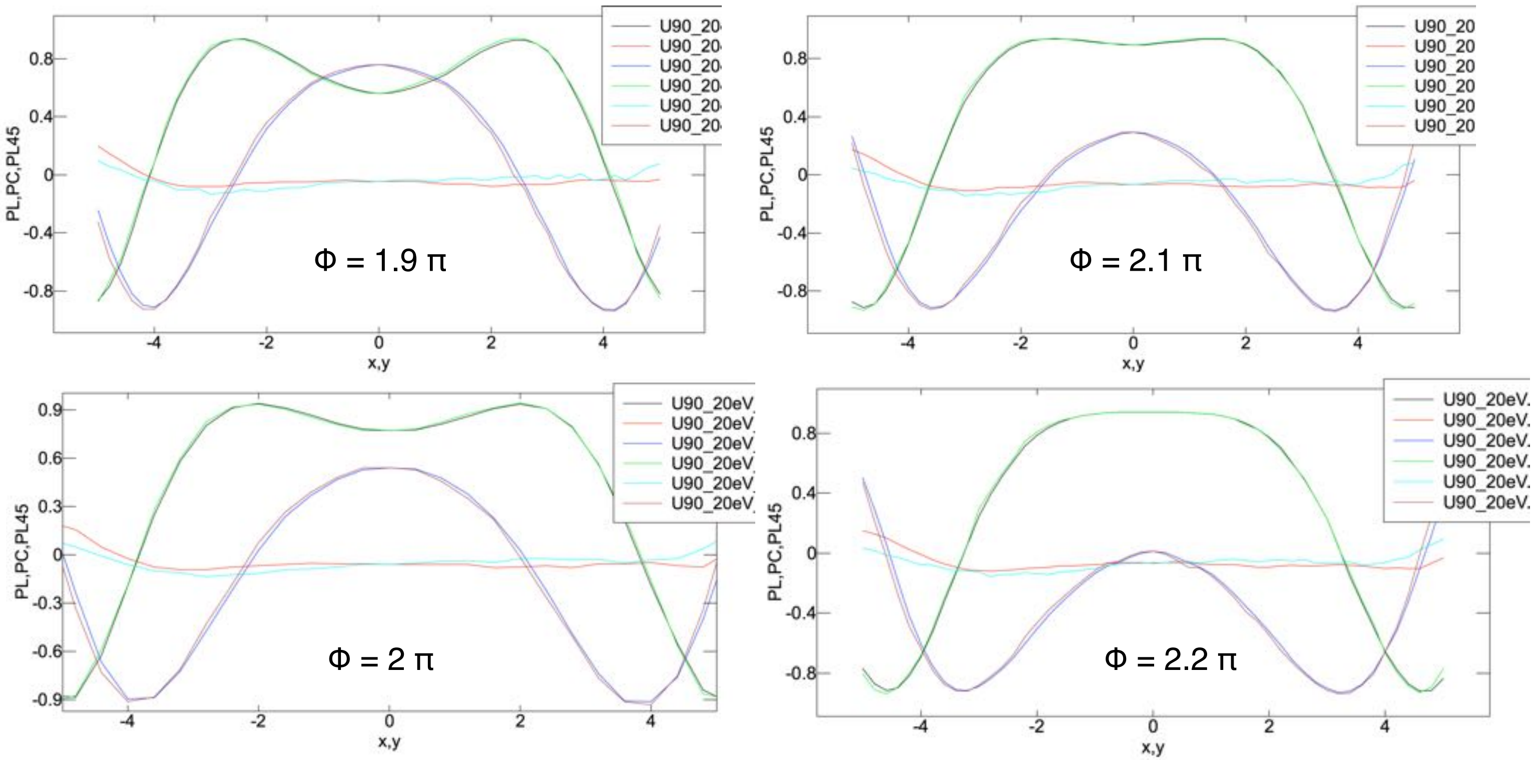

3.6e+12
2.7e+12
1.8e+12
9e+11
0
Flux
10
20
30
40
50
Energy
Flux in 1x1mm at 25m
40 x 40 µrad


UE90
LH in crossed mode
Flux
5e+14
4e+14
3e+14
2e+14
1e+14
0
11.2
11.6
12
12.4
12.8


UE90
Circ
Flux
1e+15
8e+14
6e+14
4e+14
2e+14
0
11.2
11.6
12
12.4
12.8


PL
PC
PL45
PL,PC,PL45
0.8
0.4
0
-0.4
-0.8
11.2
11.6
12
12.4
12.8
Energy

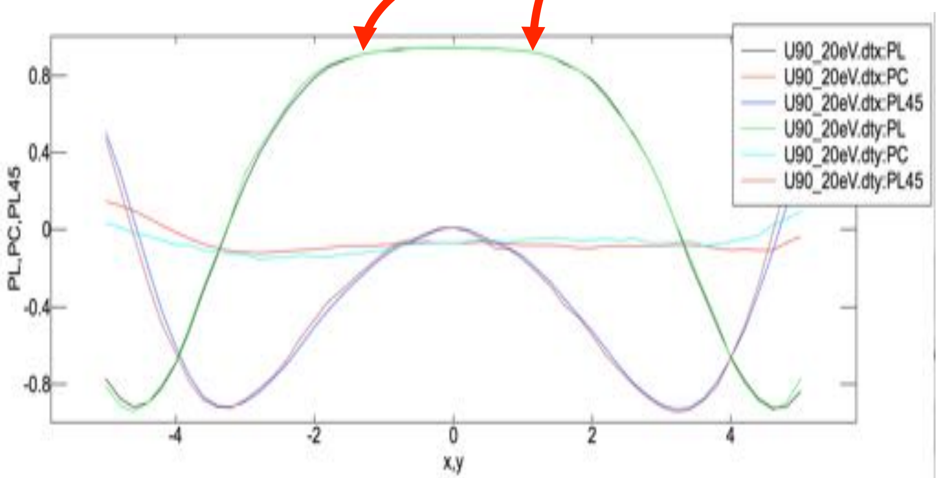

PL
PC
PL45
PL,PC,PL45
0.8
0.4
0
-0.4
-0.8
11.2
11.6
12
12.4
12.8
Energy



Stokes Parameter for different phases between crossed undulators

x,y in 25m distance from source point

Energy [eV]	B_{circ} / B_{LH} [T]	K_{circ} / K_{LH}	Aperture @25m [mm x mm]	$Flux_{Crossed}$ P > 80% [x 10^{14}]	Aperture @25m [mm x mm]	$Flux_{Crossed}$ P > 70% [x 10^{14}]	Aperture @25m [mm x mm]	$Flux_{LH}$ P 100% [x 10^{14}]
12	0.84 / 1.19	7.05 / 9.98	4 x 4	3.2	5.6 x 5.6	6	10 x 10	15
20	0.65 / 0.92	5.45 / 7.70	3 x 3	2.9	4 x 4	5.3	9 x 9	16
40	0.45 / 0.64	3.79 / 5.35	2 x 2	2.4	2.8 x 2.8	4.9	8 x 8	18
60	0.36 / 0.51	3.04 / 4.29	1.6 x 1.6	2.3	2.24 x 2.24	4.4	6 x 6	18
90	0.29 / 0.41	2.41 / 3.41	1 x 1	1.3	1.76 x 1.76	3.9	4 x 4	15



Pros

- No on-axis harmonics
- better than quasi-periodic
- No on-axis heat load

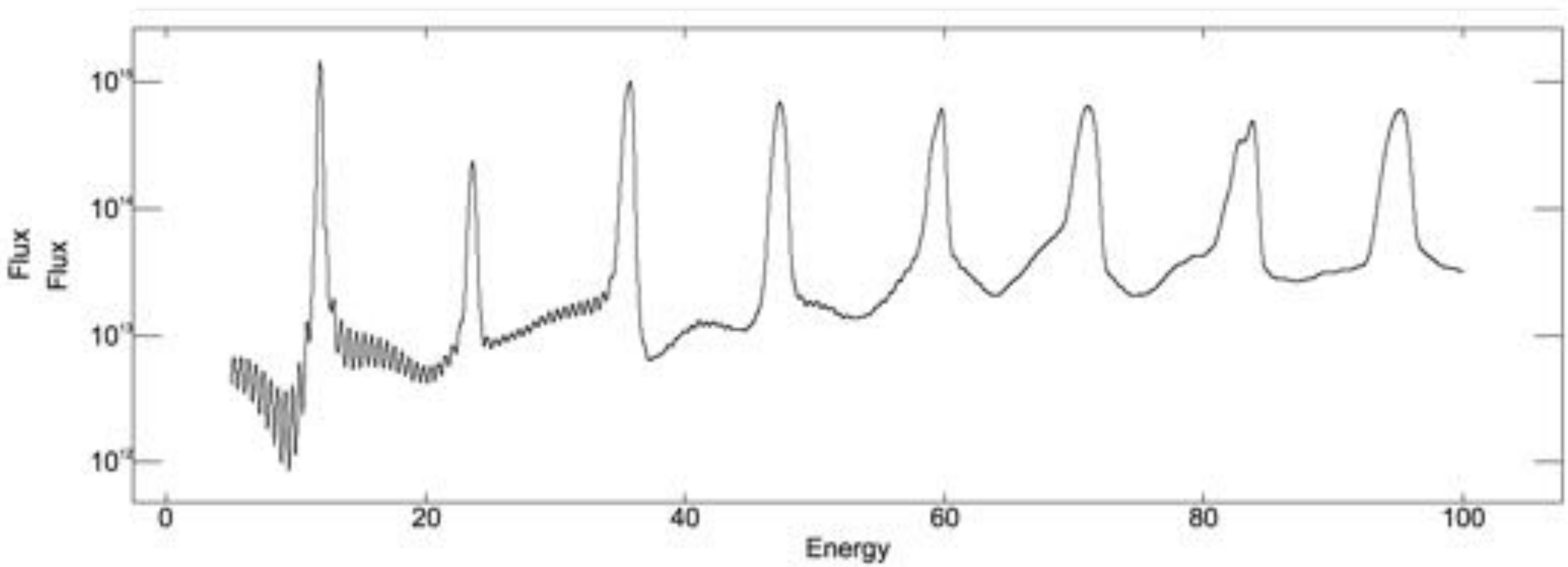
Cons

- 5 x less flux at 12eV
- 10 x less at 90eV
- degree of polarization 80%

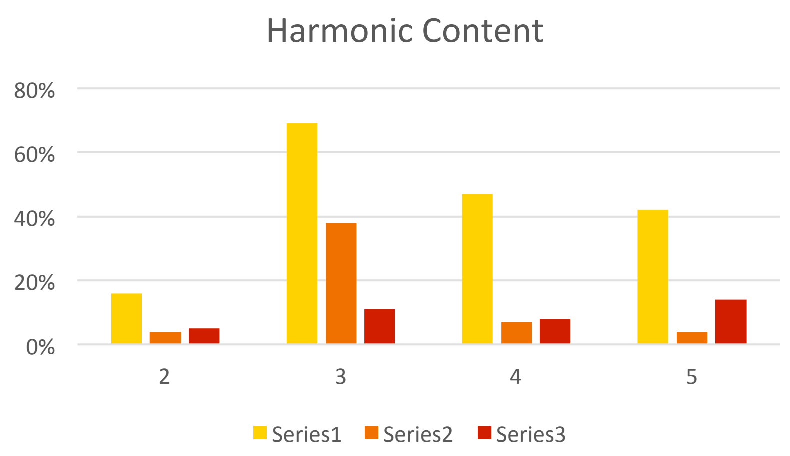
Scheme with 2 undulators allows to use both modes

Depending on photon energy, flux and polarization demand by the users

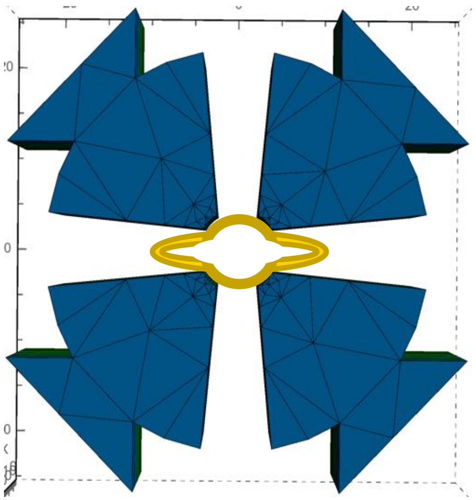
UE90 blue edge



1	2	3	4	5
1.46E+15	2.30E+14	1.00E+15	6.90E+14	6.10E+14
	16%	69%	47%	42%
7.67E+14	3.22E+13	2.90E+14	5.70E+13	3.40E+13
	4%	38%	7%	4%
3.60E+14	1.64E+13	3.86E+13	2.70E+13	5.20E+13
	5%	11%	8%	14%



Vacuum chambers for APPLE X at storage rings



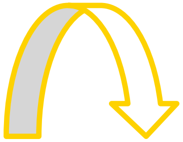
Vacuum chambers for single pass machines:

round, simple

Injection requires larger horizontal apertures

vacuumchambers with antechambers

complicated to impossible



from undulator point of view

On-axis injection schemes highly desireable

Various on-axis injector schemes under development at ALS, BAPS, SOLEIL, SLS

Only when these schemes are in baseline a project can profit!

ADRESS UE44

fixed gap APPLE II

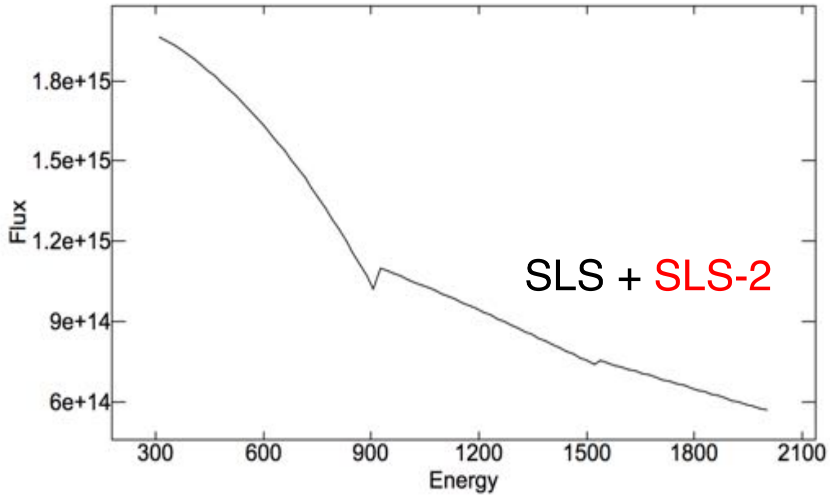
Upgrades required:

Add cam-shaft mover

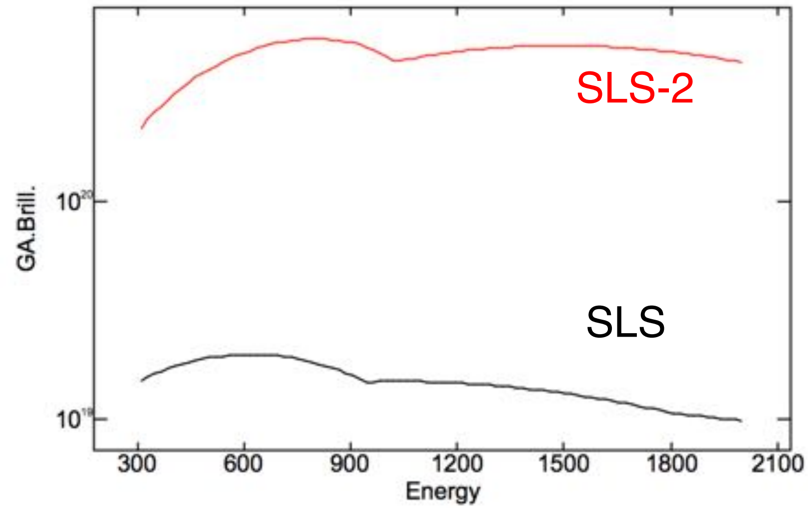
to allow (in situ) alignment

UE44 SLS to SLS-2

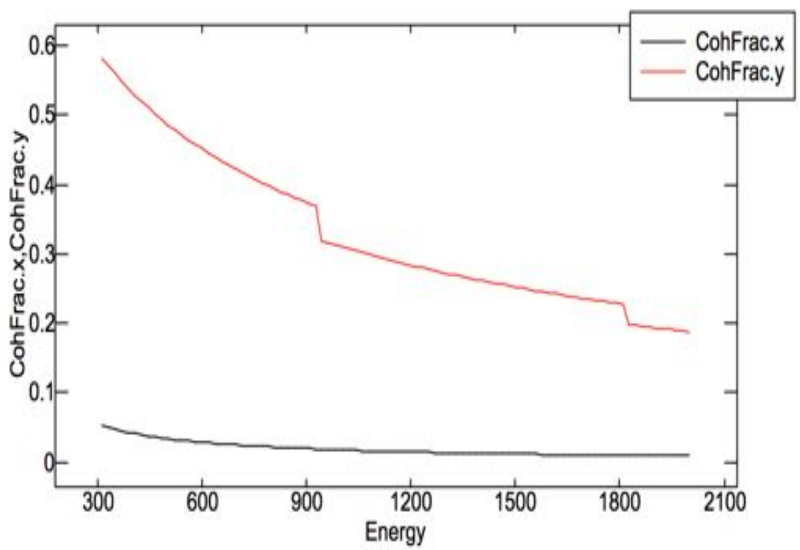
Flux



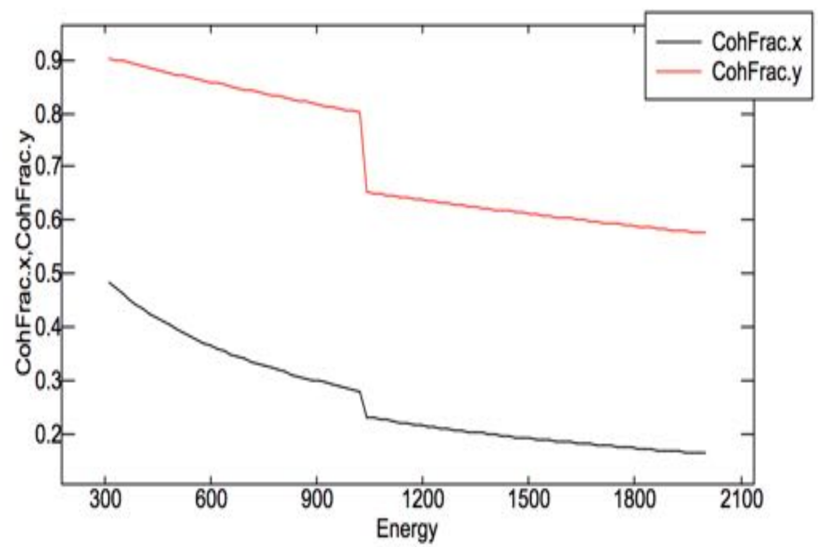
Brilliance



Coherent fraction SLS

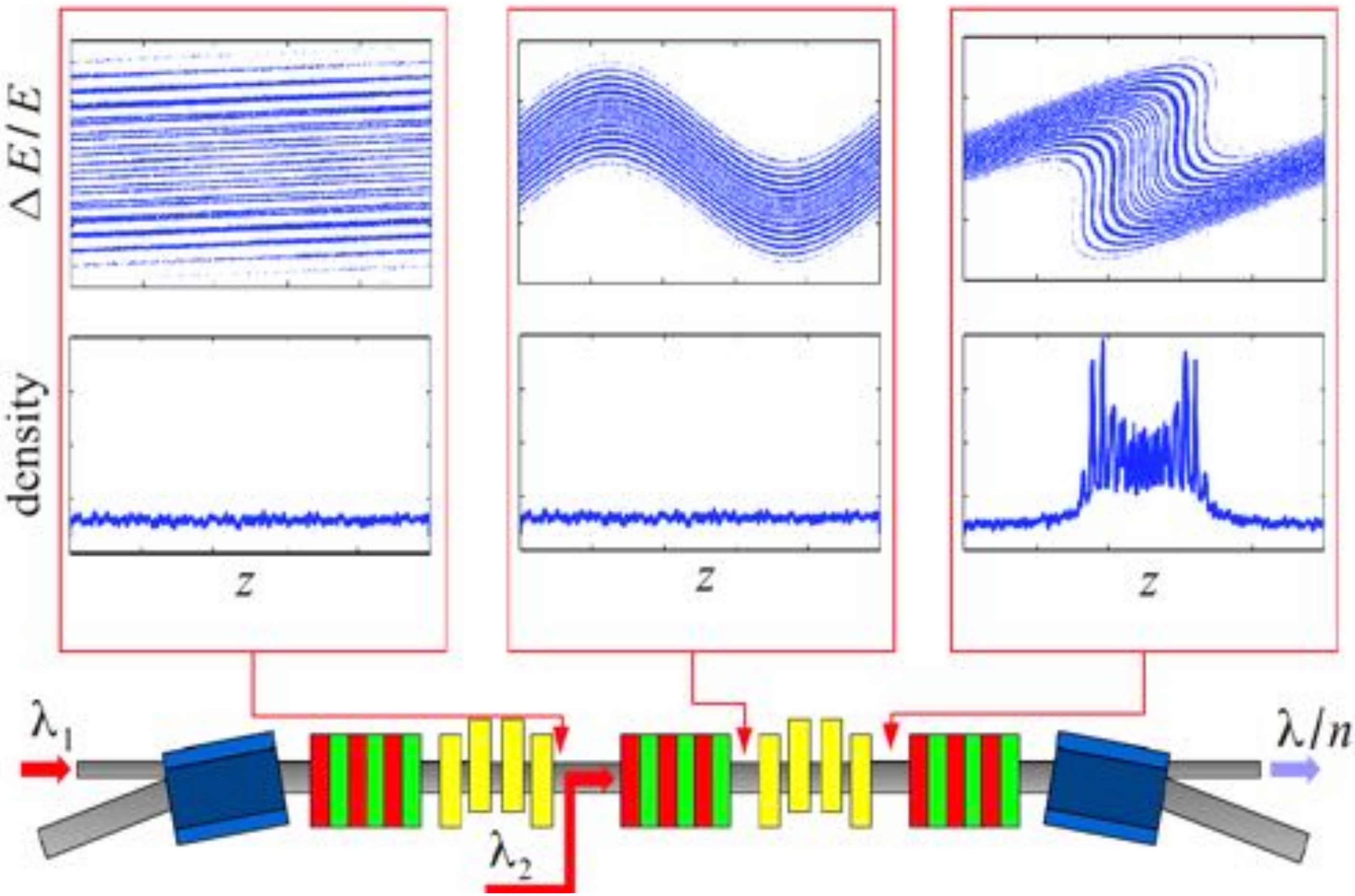


SLS-2



EEHC for ADRESS

Echo **E**nabled **H**armoni**c** Generation



R. Molo et al., ECHO-ENABLED HARMONIC GENERATION AT DELTA, Proceedings of IPAC2011, San Sebastián, Spain

EEHC for ADRESS

EEHC in SLS-2 in 2 straights

Straight 1

Rf cavities + modulator 1

Arc which is the dispersive element R_{56}

Straight 2

modulator 2 + phase matcher + APPLE X

A unique opportunity for SLS-2!

negligible increase of energy spread

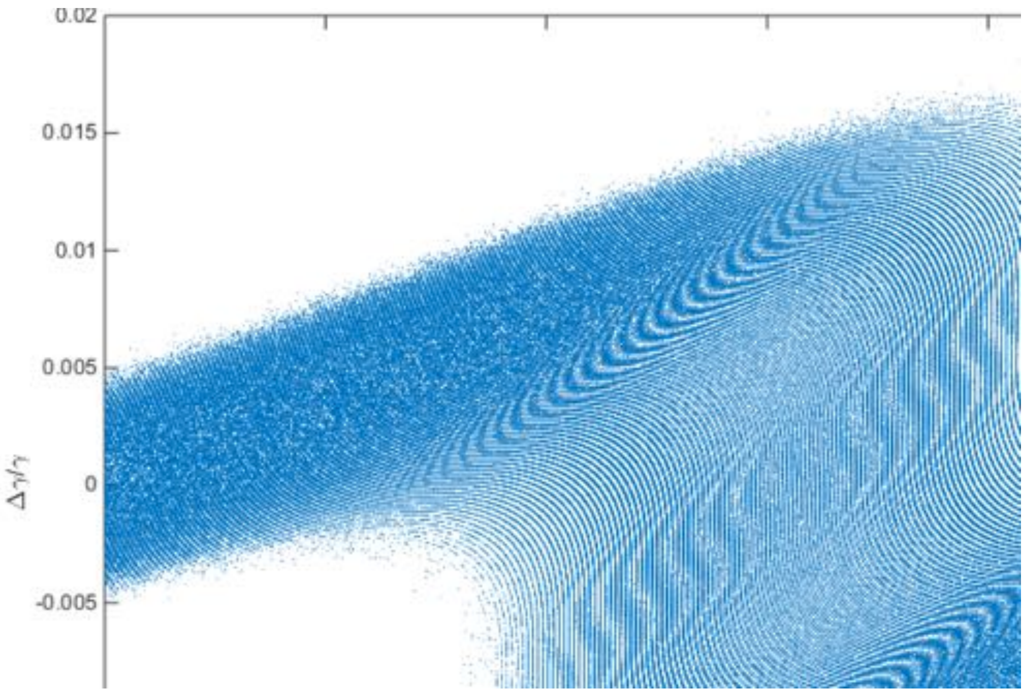
Note: EEHC developed for FEL

Studies for

Hefei storage ring, DELTA, SLS-2, ...

about 1% density modulation

Increase in coherent flux: 100-10000



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SIM UE56 / Phoenix, X-treme UE54

APPLE II

UE56 twin undulators

UE54 serves two beamlines

X-treme soft x-ray

Phoenix tender x-ray

37th harmonic !!!

SLS-2 lattice allows a second undulator

Hydraulik Drive for shift gap axis

Hydraulik driven Cylinder as alternative to motor/spindel drive system

System: Bosch Rexroth 4WRPDH

valve with integrated regulation and interfaces or µ-controller with valve

resolution valve: 0.001%

cycle time: <1ms

regulations:

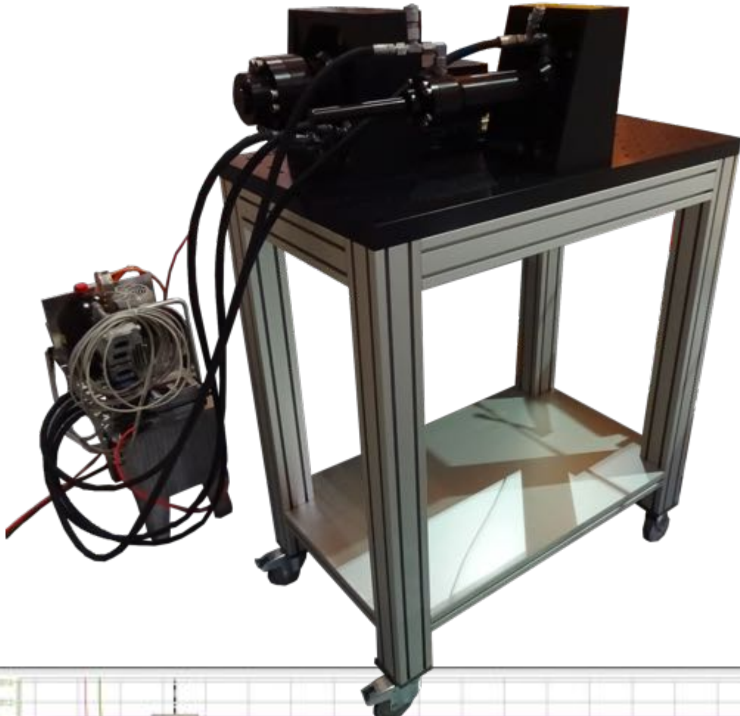
- position
- force
- pressure
- positon/pressure, position/force

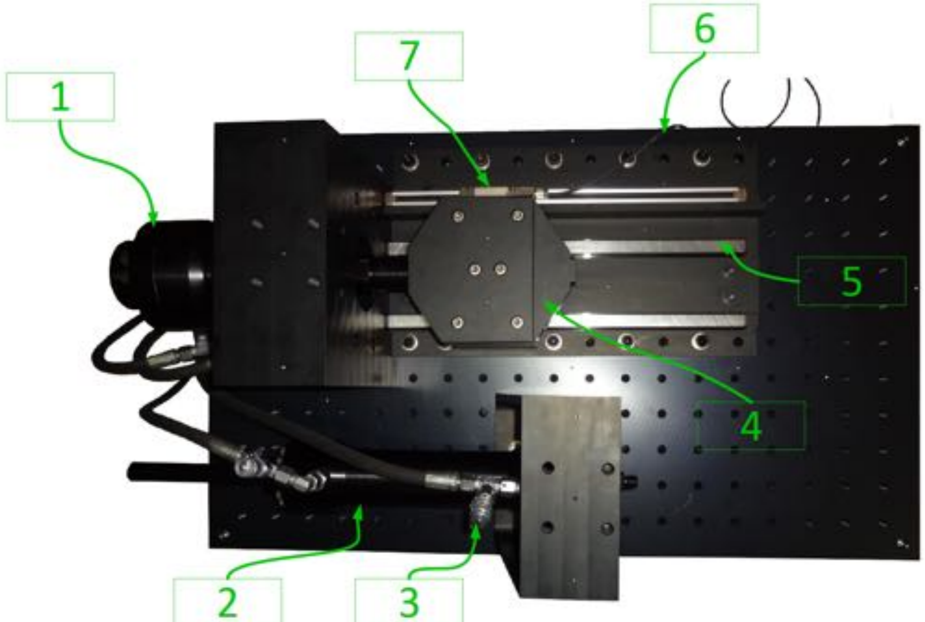
connecitons:

EtherCAT, EtherNet, PROFINET, …

https://www.boschrexroth.com/de/de/produkte/produktgruppen/industriehydraulik/stetigventile/regel-wegeventile/direktgesteuert/integrierter-achsregler/iac-multi-ethernet/iac-multi-ethernet

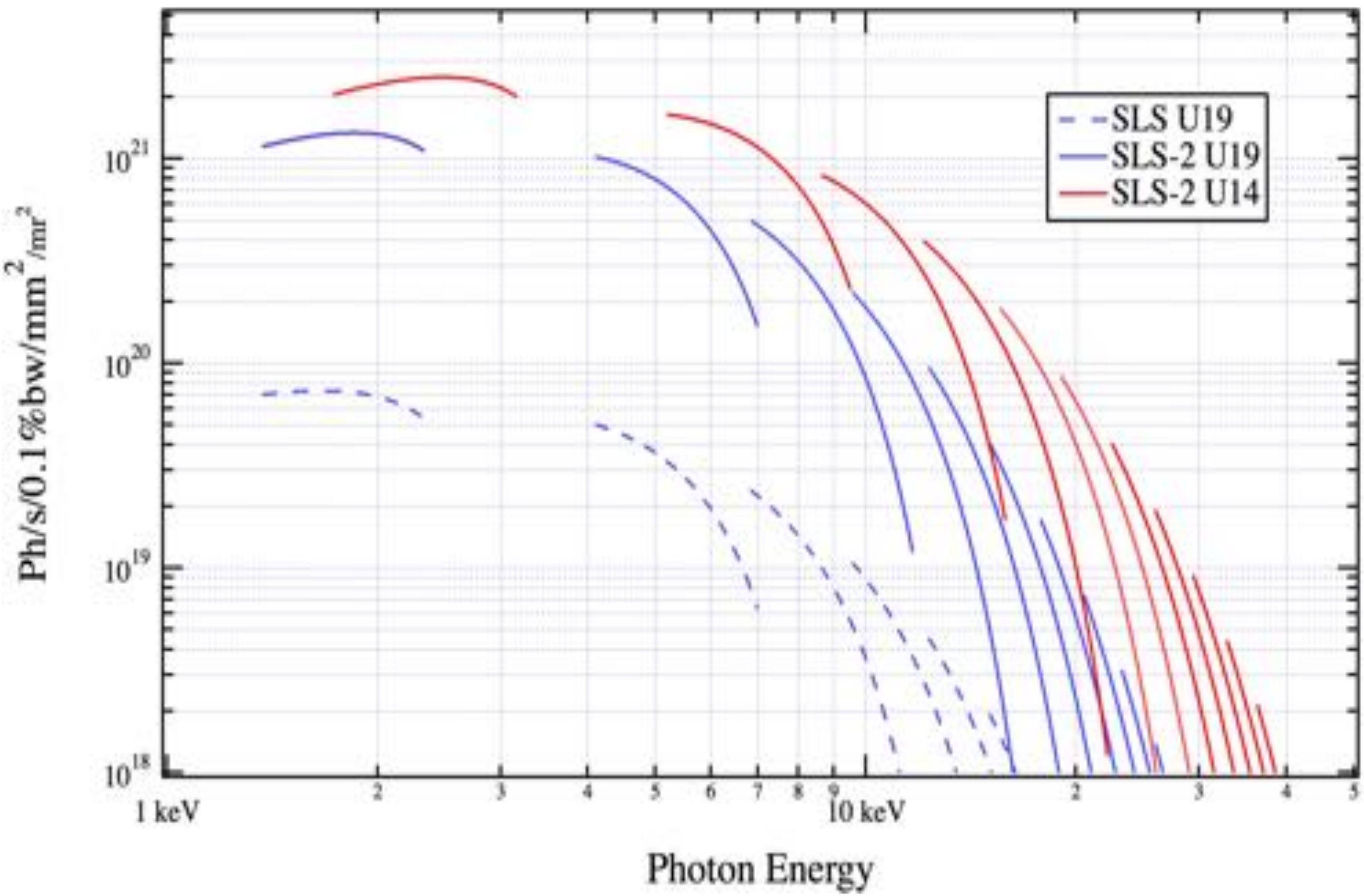
Hydraulik Test Stand



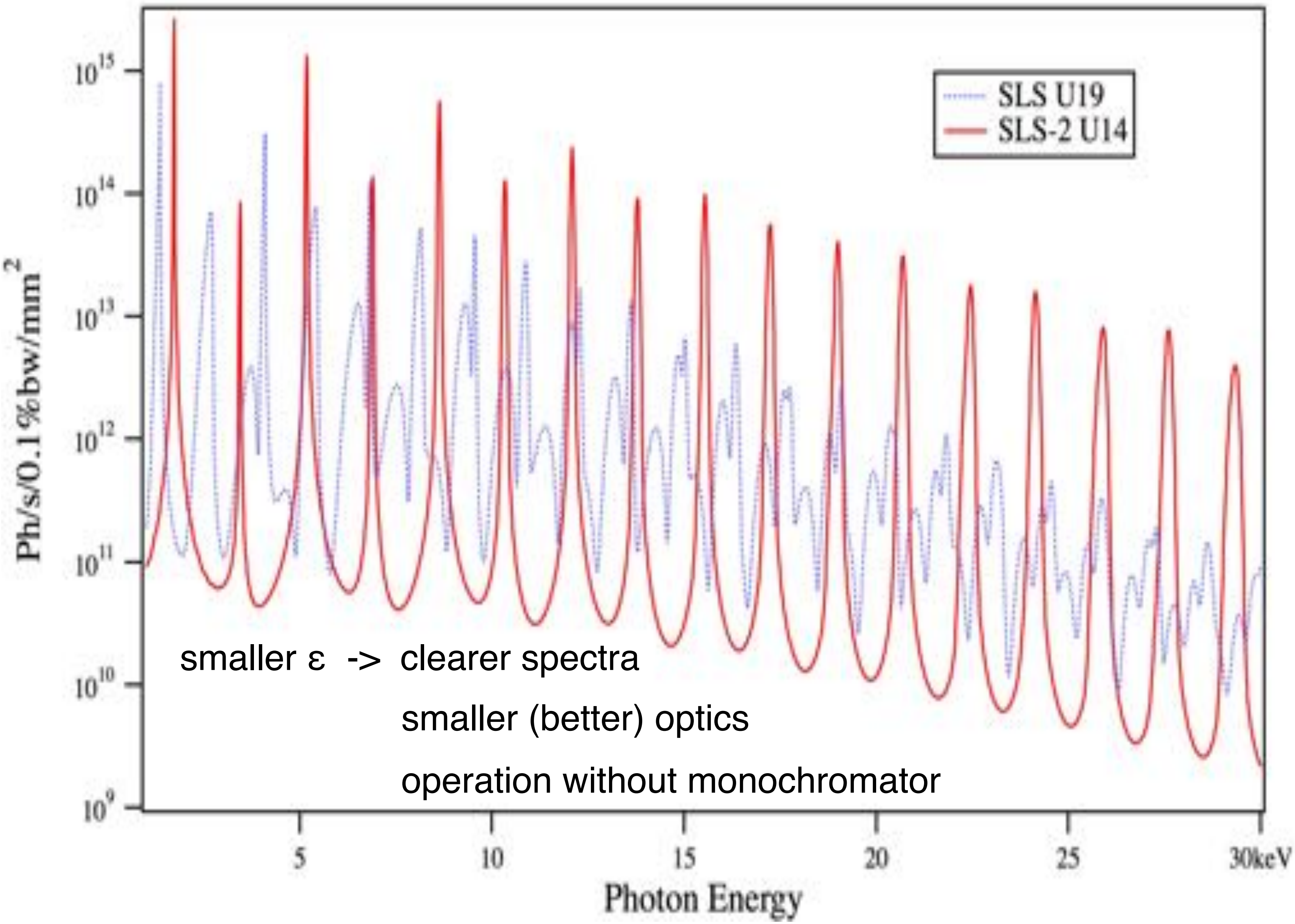


PX, c-SAXS, µ-XAS U19 / MS U14

SLS-2 Brilliance



SLS-2 Spectra



PAUL SCHERRER INSTITUT

SLS-2 strategy for hard x-ray undulators

U19 in Vacuum Undulatoren -> Cryo Undulatoren CPMU14
based on PrFeB

Upgrade of the existing in-vacuum undulators

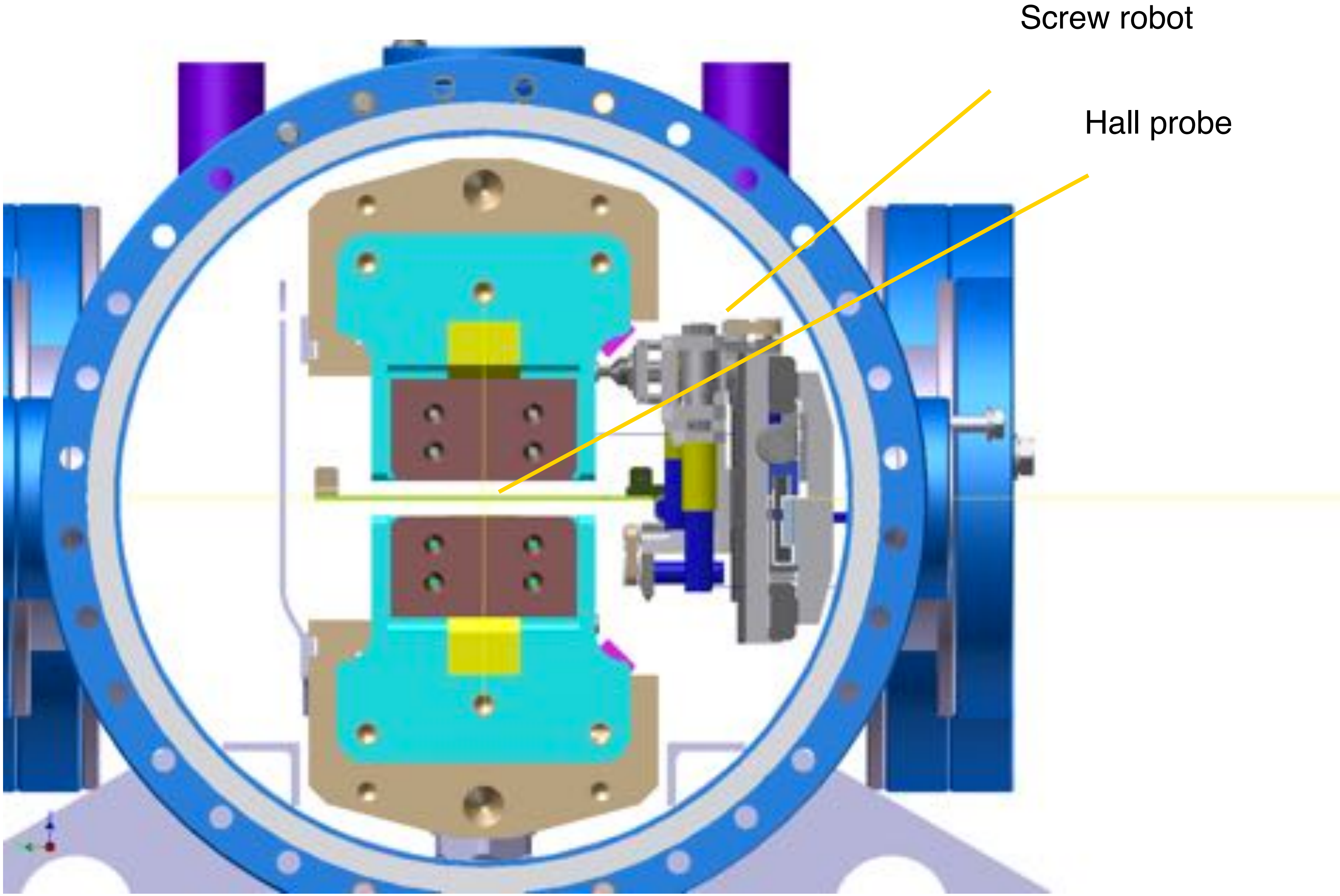
Higher fields, but smaller horizontal pole widht <- small emittance

needs to be realized in the year 2023 machine dark time

CPMU14 based on NdFeB at 135K: no change

All in-vacuum undulators can be installed in any place

In-situ Measurement / Optimization Bench



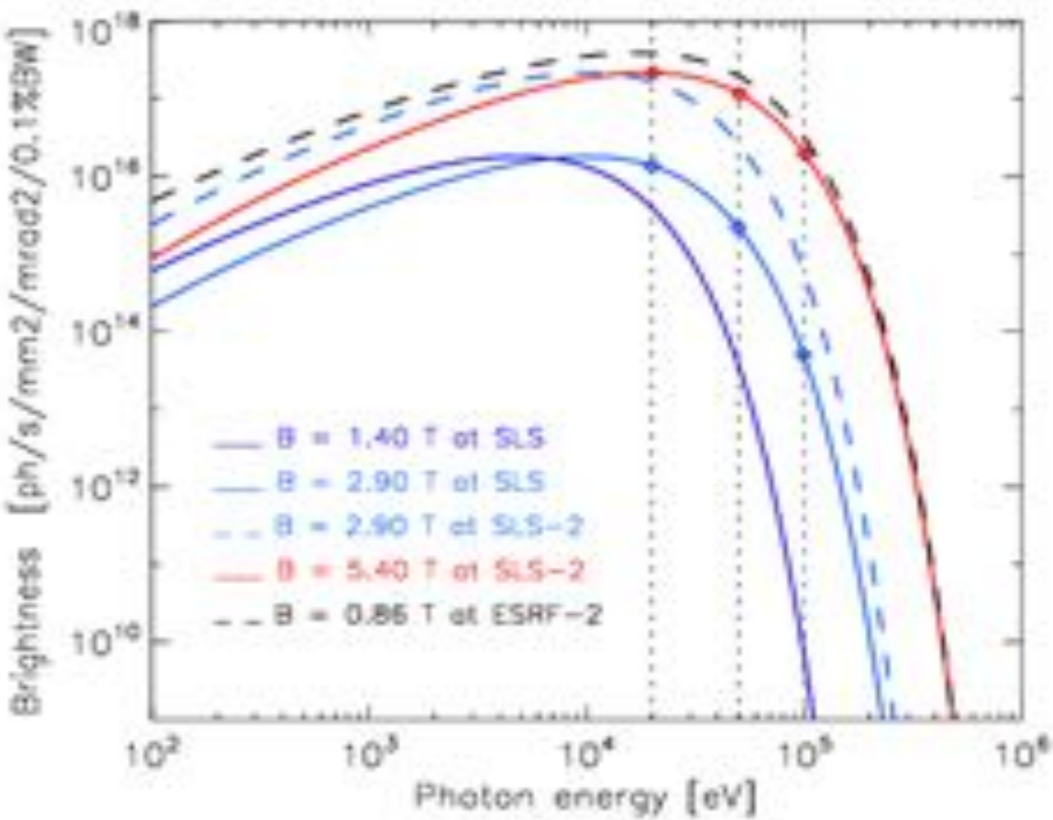
SLS – SLS-2 Reference table

		@ Energy	Brilliance	Flux	Flux dens	coh. Flux x	y	tot Power [kW]	Brilliance increase
ADRESS	**SLS**	600	2.00E+19	1.60E+15	2.60E+17	0.03	0.45	4.3	
UE44	**SLS-2**	800	6.00E+20	1.60E+15	7.60E+17	0.38	0.84		30.00
SIM	**SLS**	500	1.70E+19	1.50E+15	2.30E+17	0.03	0.48	4.0	
UE56	**SLS-2**	500	4.00E+20	1.50E+15	6.80E+17	0.41	0.86		23.53
PHOENIX/X-treme	**SLS**	500	7.00E+18	7.00E+14	8.80E+16	0.03	0.39	1.8	
UE54	**SLS-2**	500	1.50E+20	8.00E+14	2.00E+17	0.33	0.83		21.43
SIS UE212	**SLS**	60 / 150	1.6E18 / 3.3E18	1.00E+15	7E16 / 9E16	0.23	0.92	1.9	
UE90	**SLS-2**	60 / 400	9.4E18 / 1.3E20	1.20E+15	7E16 / 2.8E17	0.83	0.97	8.3	39.39
PXI/II, cSAXs, µ-XAS	**SLS**	8000	8.00E+18	3.00E+14	4.90E+16	0.002	0.07	2.3	
U19	**SLS-2**		3.70E+20	3.00E+14	2.56E+17	0.040	0.18		46.25
	SLS	12000	3.00E+18	1.10E+14	1.80E+16	0.001	0.05		
	SLS-2		1.40E+20	1.10E+14	9.50E+16	0.030	0.12		46.67
	SLS	20000	4.80E+17	1.70E+13	3.00E+15	0.001	0.03		
	SLS-2		2.20E+19	1.70E+13	1.45E+16	0.020	0.07		45.83
MS	**SLS**	8000	1.66E+19	5.70E+14	9.30E+16	0.002	0.07	1.8	
U14	**SLS-2**		8.80E+20	5.90E+14	6.20E+17	0.040	0.18		53.01
	SLS	12000	8.60E+18	3.20E+14	5.00E+16	0.001	0.05		
	SLS-2		4.30E+20	3.20E+14	2.90E+17	0.030	0.12		50.00
	SLS	20000	2.20E+18	8.10E+13	1.30E+16	0.001	0.03		
	SLS-2		1.10E+20	8.10E+13	7.50E+16	0.020	0.07		50.00

Calculated with Spectra 10.0

Note: for SIS the SLS-2 calculations are based on a UE90 instead of a UE212

Super longitudinal gradient bending

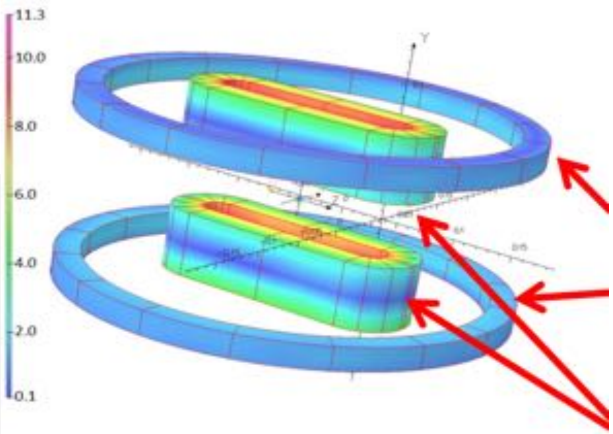


for ±0.5 mrad fan angle
full vertical acceptance

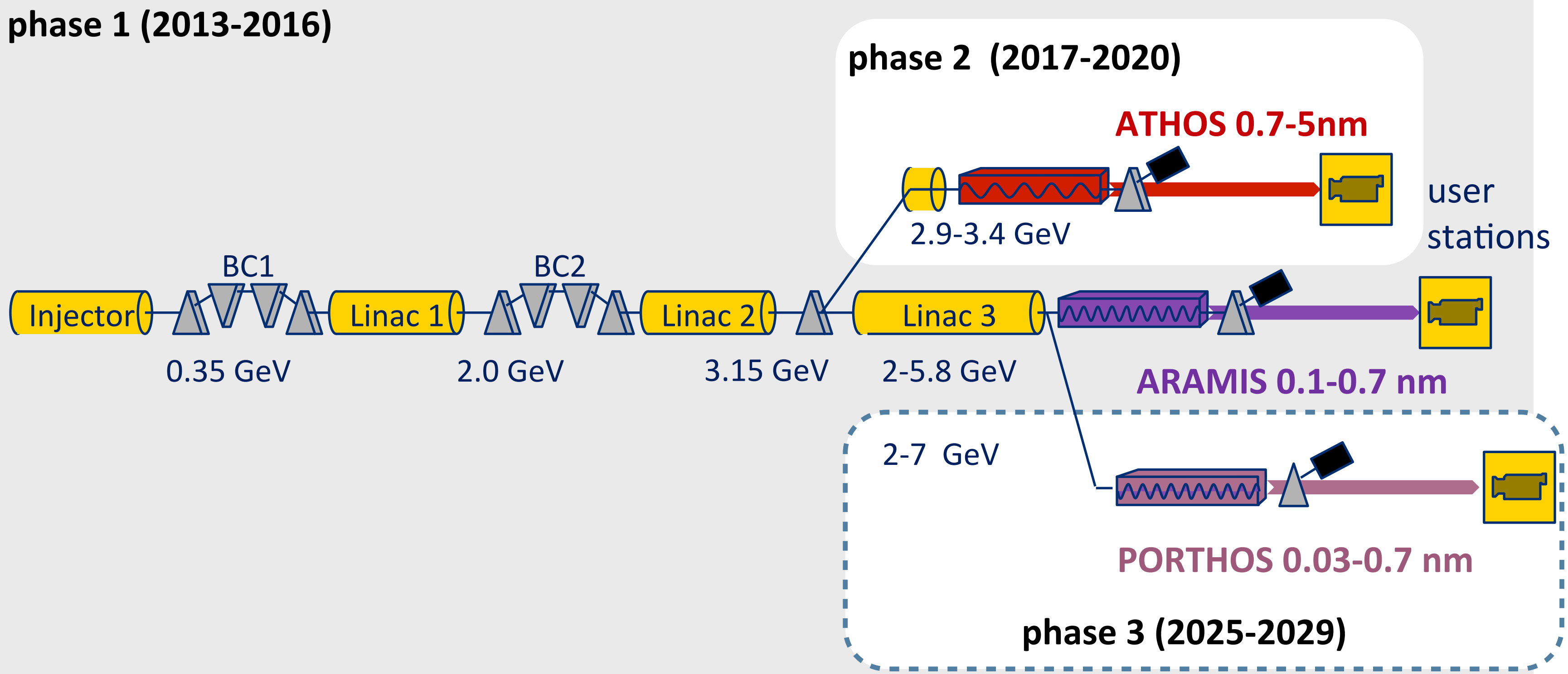
- 2.9 T at SLS
- 5.4 T at SLS-2

- - ESRF-EBS (6 GeV) 0.86 T 2-pole wiggler

Superconducting dipoles



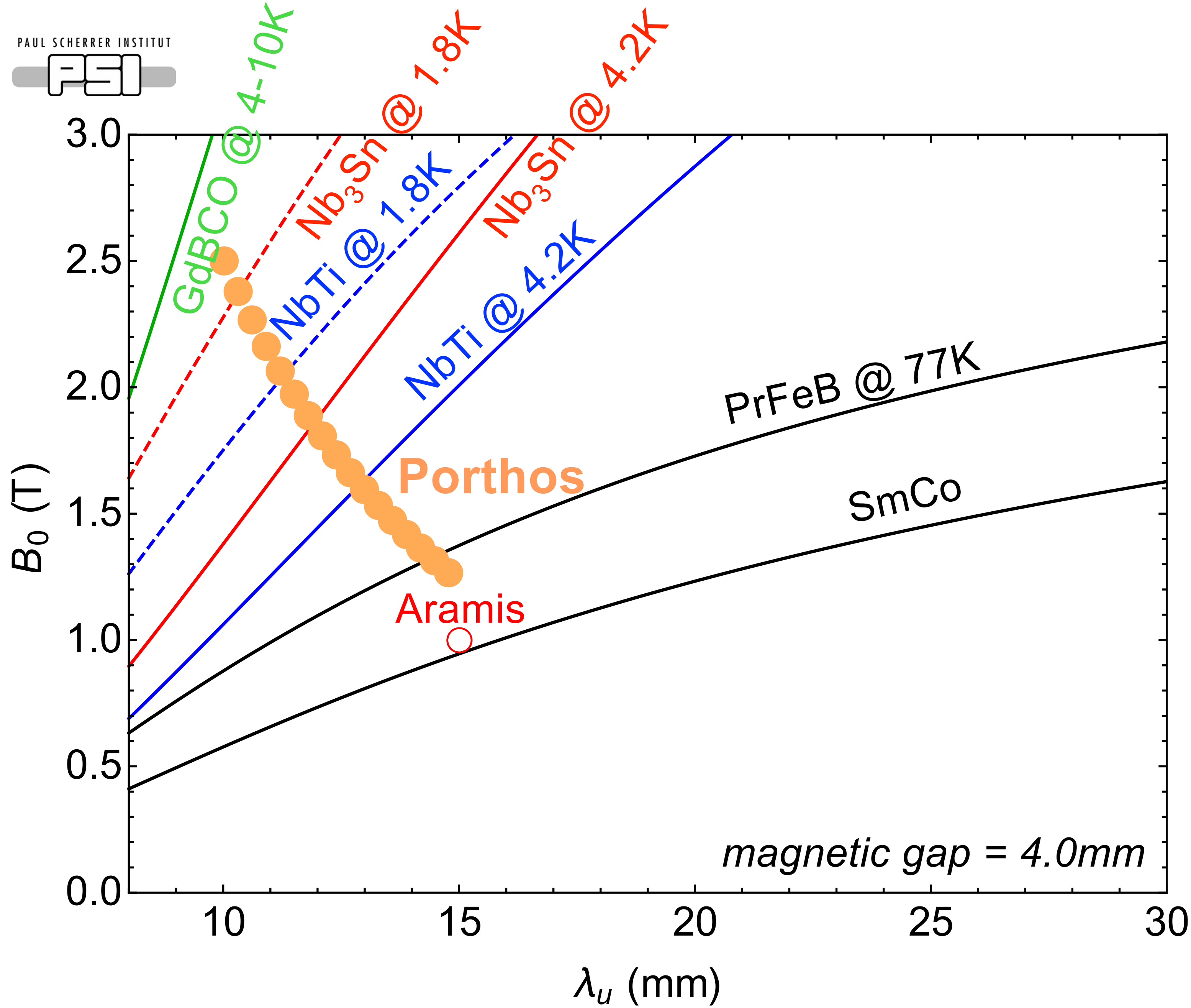
SwissFEL Outlook



Supraleitende Undulatoren U10

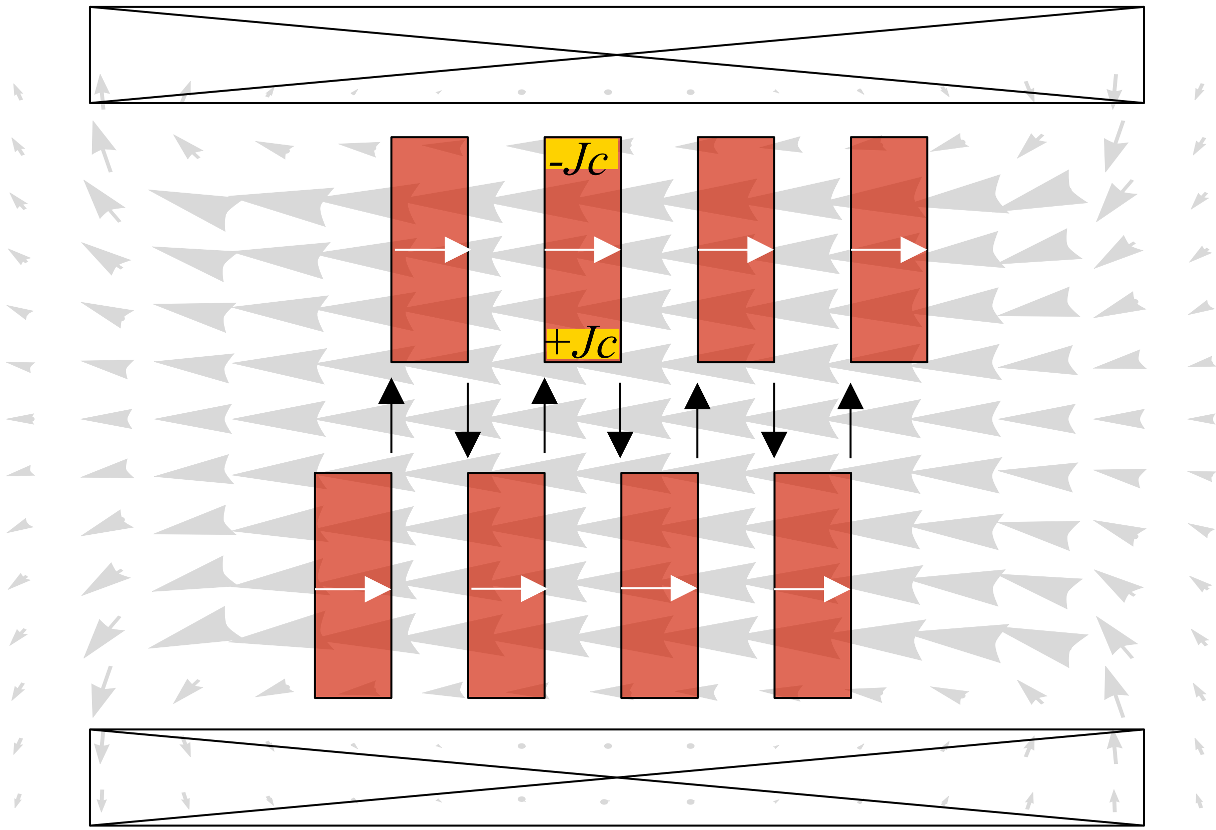
(4K – flüssig He)

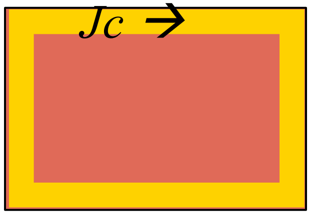
Einsatz auch in SLS-2 für Micro-Tomcat



E.R. Moog, R.J. Dejus, and S. Sasaki , Light Source Note: ANL/APS/LS-348
James Clarke, FLS 2012, March 2012

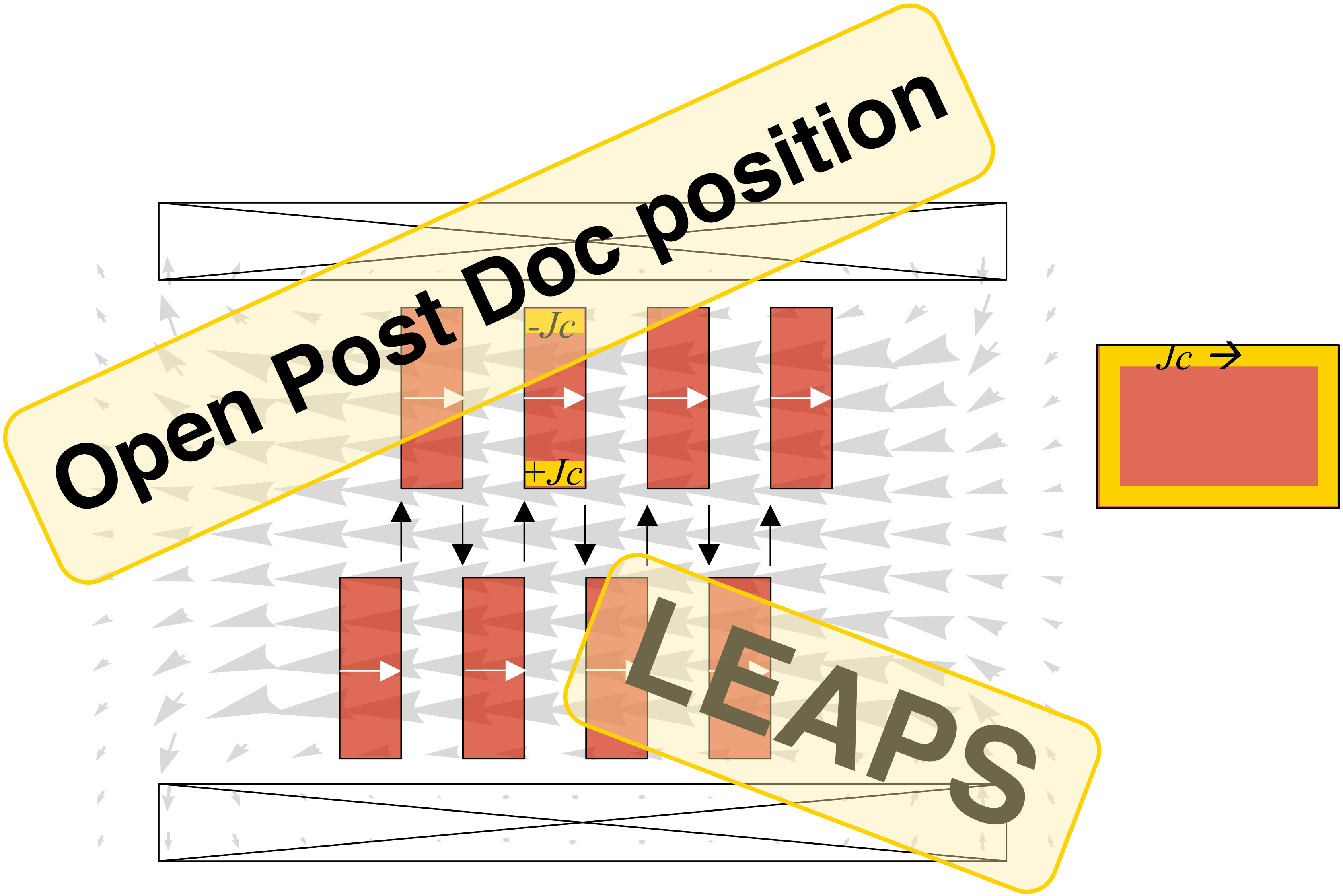
Staggered array with HTS bulks





C.P.Bean, Rev. Mod. Phys. 36 (1964) 31.

Staggered array with HTS bulks



C.P.Bean, Rev. Mod. Phys. 36 (1964) 31.

Thanks for your interest

and special thanks to

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T. Tanaka for SPECTRA