The BESSY III Lattice

A highly competitive non-standard lattice for a 4th gen. Light Source with Metrology and Timing Capabilities

P. Goslawski for the CDR, accelerator & lattice design team

(M. Arlandoo, **M. Abo-Bakr, B. Kuske, J. Bengtsson, J. Völker**, V. Dürr, A. Jankowiak et al.,)
(K. Holldack, Z. Hüsges, K. Kiefer, A. Meseck, R. Müller, M. Sauerborn, O. Schwarzkopf, J. Viefhaus et al.,)

HZB BESSY II Light Source

Pre-CDR
DOI: 10.5442/r0004

Combined function or Homogenous bend

Two partners & two synchrotron radiation sources

HZB Helmholtz Zentrum Berlin

BESSY II

1.7 GeV, DBA,
5 nm rad, 300 mA
240 m, 16 Straights, 5 m
since 1998

Soft and tender X-rays
Spectro-Microscopy
Timing: low α, femto-slicing
SB, VSR, TRIBs/2-Orbits

Fernsehturm am Alexanderplatz

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

MLS Metrology Light Source

630 MeV, DBA
100 nm rad, 200 mA
48 m, 4 Straights
since 2007

THz / IR to VUV, EUV
Optimised for low α,
SSMB studies

Talk by D. Xiujie on Wednesday
Low Long. Emittance and SSMB Storage Rings

Solar Energy	Chemical Energy	Quantum & Functional Materials
Photon Science	Accelerators	Scientific Instrumentation & Support


Lithography Optics Division
CARL ZEISS SMT

Acknowledgment

Thanks to a huge team effort at…

- FOM-Rijnhuizen
- TNO TPD
- PTB-BESSY
- IWS Dresden
- Philips
- Heidenhain
- The teams at ASML and Zeiss
- …and many others

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Bundesministerium für Bildung und Forschung

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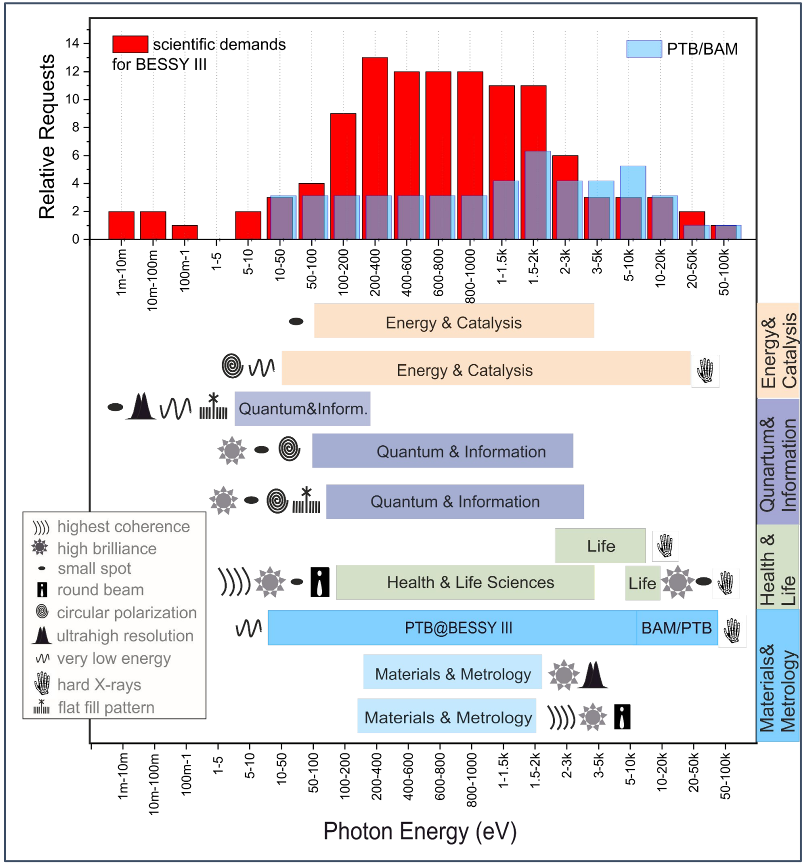
ASML

BESSY III Objectives & Requirements



Facility parameters

1. 1st undulator harmonics polarized up to 1 keV from conventional APPLE-II
2. Diffraction limited till 1 keV
3. Stay in Berlin-Adlershof
4. Nanometer spatial res. & phase space matching
5. PTB/BAM metrology applications

Already at BESSY II, a 3rd generation **without** combined function bends

Ring parameters

1. Ring Energy **2.5 GeV** (1.7 GeV)
2. Emittance **100 pm rad** (5 nm rad)
3. Circumference **350 m**
   16 straights @ 5.6 m
   (240 m @ 4.5 m)
4. Low beta straights & maybe round beams
5. **Metrology source Homogenous bends**
   Measuring the field at the source point with a NMR probe in a volume of 10x10x10 mm
6. **Momentum compaction factor** **> 1.0e-4**

1-2 bends per arc

PTB - Metrology Sources, Homogenous Bends

(Physikalisch Technische Bundesanstalt)

Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

ZEISS ASML

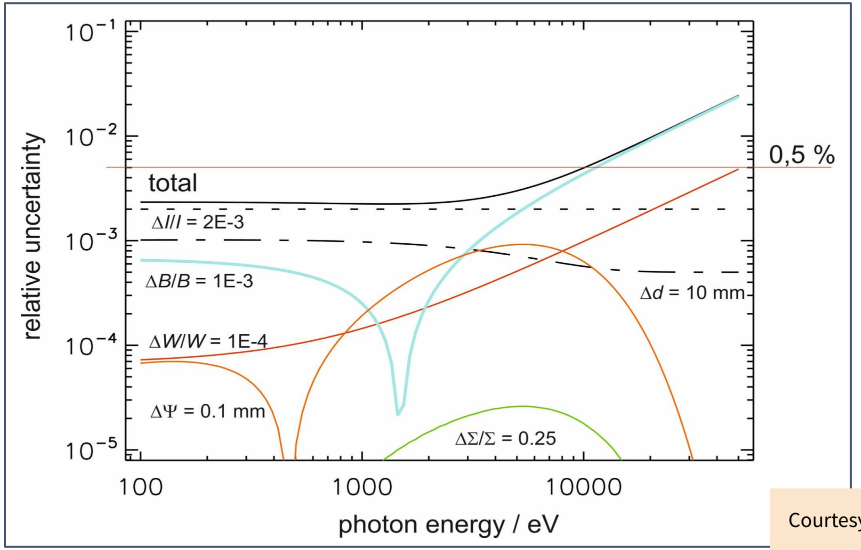
EUV Litography system (200 - 300M€)

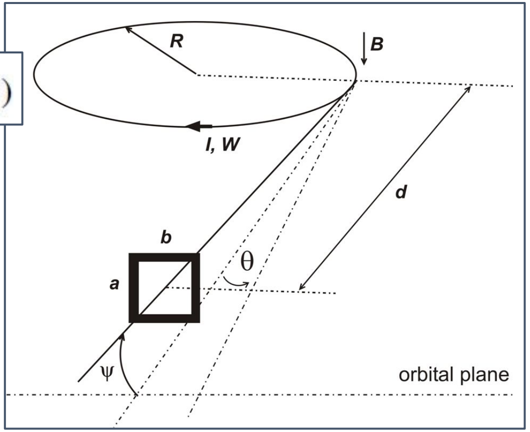
An absolute measurement of the radiation power with highest accuracy

- Schwinger equation with its parameters
  - Electron Energy W with rel. unc. < 5e-4
  - Electron Current I with rel. unc. < 2e-4
  - Magnetic Field B with rel. unc. < 1e-4
  - Source size & div. with rel. unc. < 20 %
  - Distance to apert. with rel. unc. ~ 2 mm

R. Klein et al., Phys. Rev. STAB 11 (2008) 110701

$$\Phi_\lambda = \Phi_\lambda(\lambda; W, B, I, \Sigma_y; y_0, d, r)$$





Courtesy R. Klein, PTB

Lattice Design - 4th Generation Lightsource Lattices

The Higher Order Achromat, HOA-MBA

- Distributed sextupoles
- MAX IV, SLS 2.0 … up to 3 GeV
  - J. Bengtsson, A. Streun, S. Leeman, et al.

The Hybrid, HMBA

- Localised sextupoles
- ESRF-EBS, PETRA IV, ALS-U , … above 3 GeV
  - P. Raimondi, …

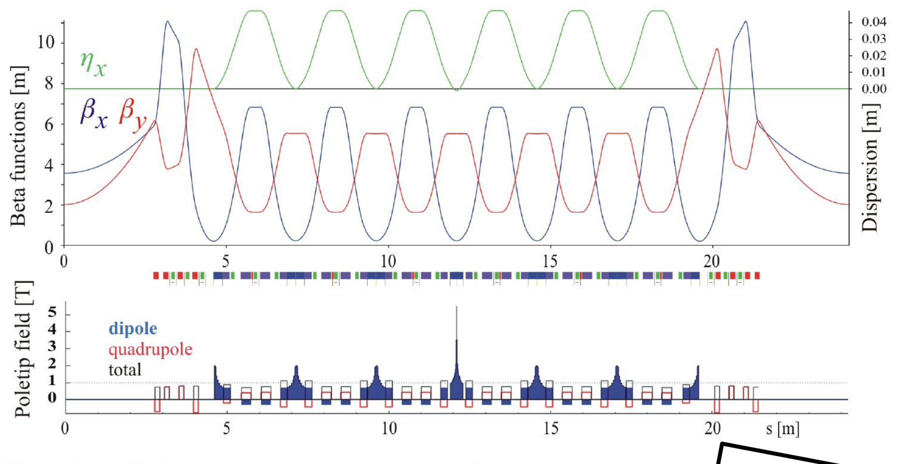
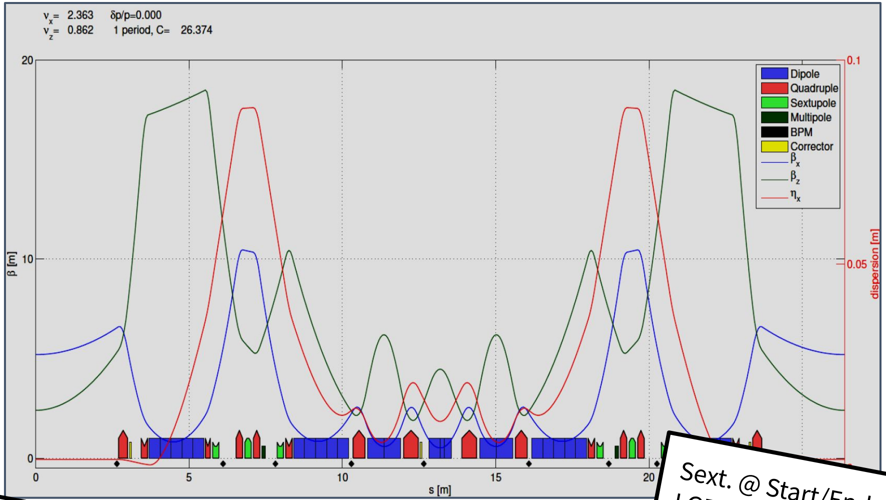


Figure 2.3: Optical functions and field components for one 7BA-arc where the center LGB … by a super-LGB of 5.5 T peak field. Bending magnets are in dark blue, quadrupoles red…

Sext. distributed
LGB - yes
RB - yes

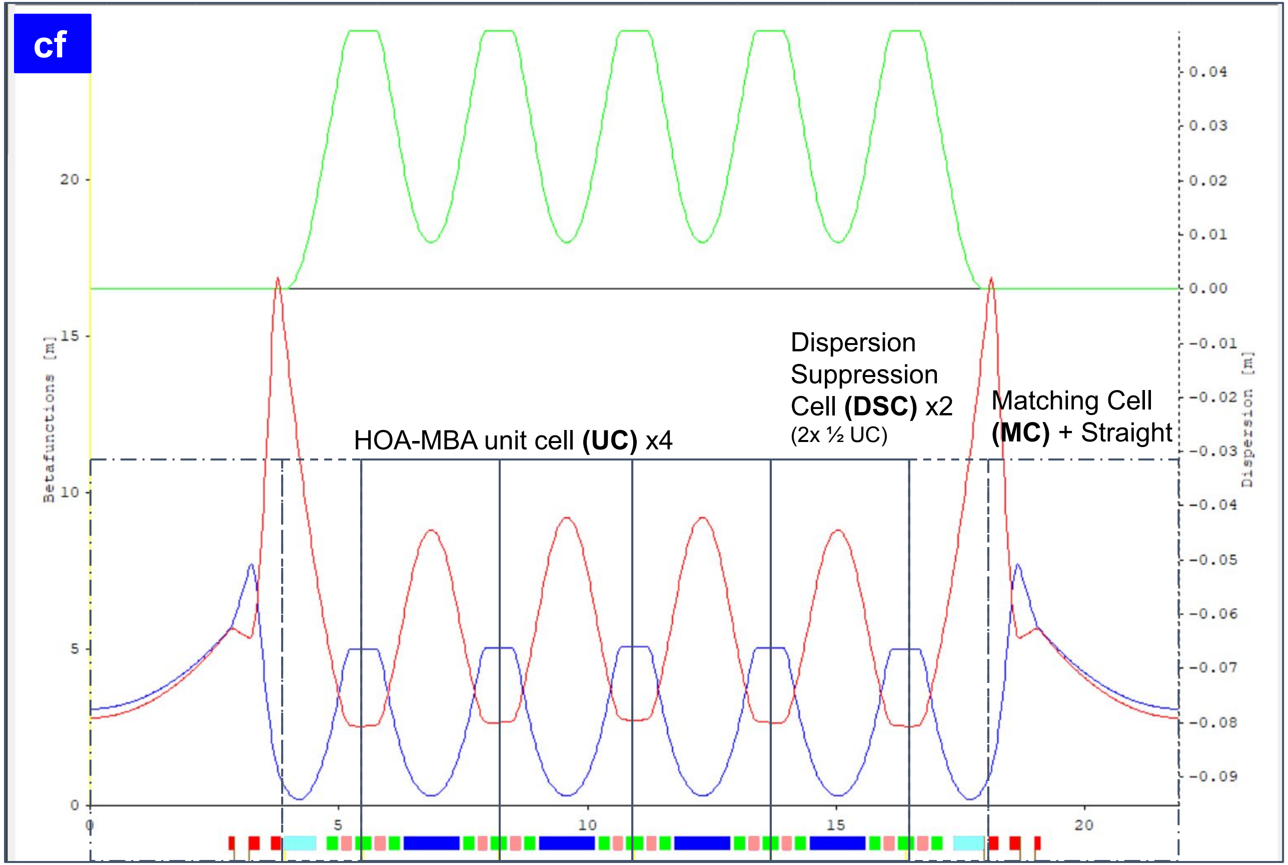


$$\epsilon_{x,e^-} \sim E^2/N_d^3$$

$$x_D = D \cdot \Delta p/p$$

Sext. @ Start/End
LGB - yes
RB - no

LEGO Approach - Basic building blocks of one sector



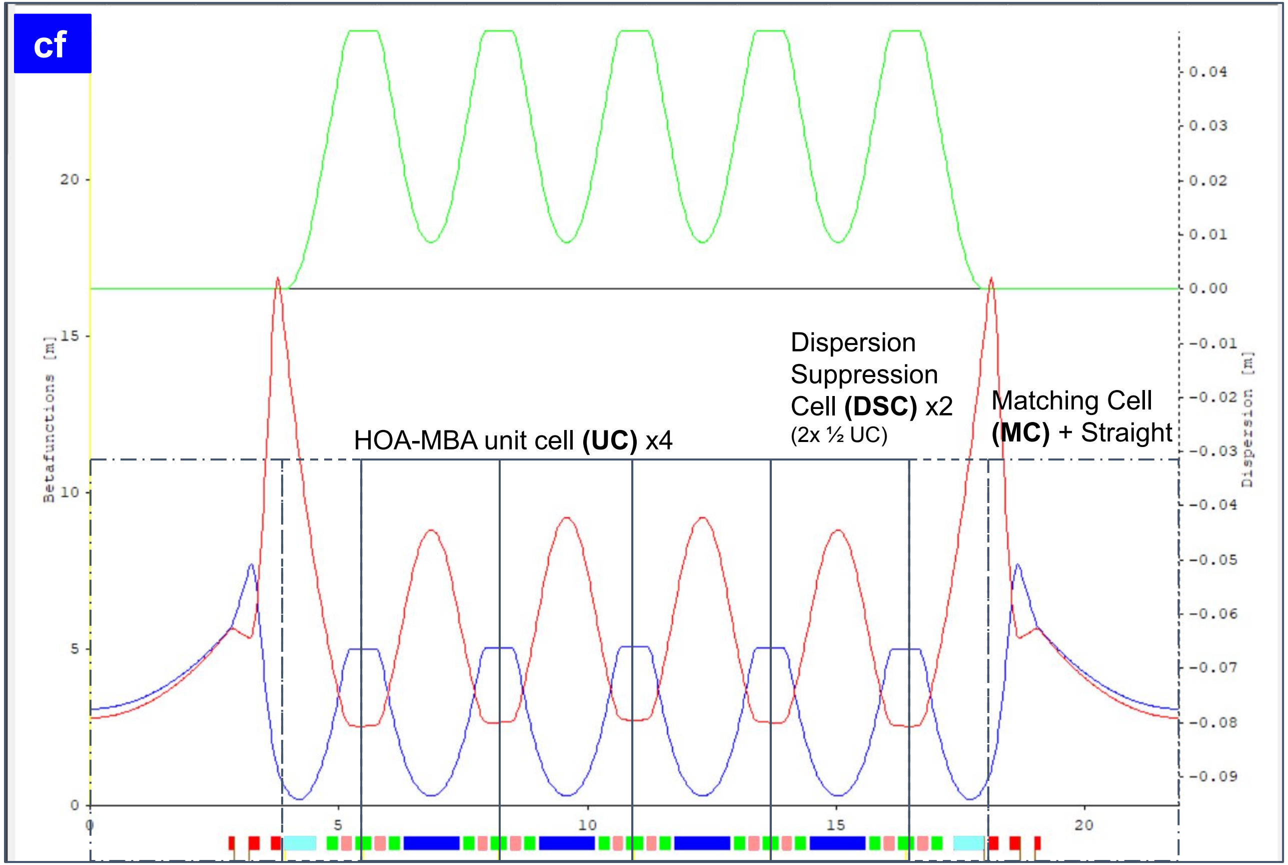
UC - Unit Cell
DSC - Dispersion Suppress..
MC - Matching Cell

A 6-MBA has 5-MBA-UC
4 pure UC and
1 (2 x ½) broken UC → DSC

16 straights & sectors:

360° / 16 = 22.5° per sector
4*4.5° main UC bend &
2*2.25° DSC bend

LEGO Approach - Basic building blocks of one sector



References:

Linear Optics Design:

B.C. Kuske, “Towards Deterministic Design of MBA-Lattices”, IPAC21, MOPAB220
B.C. Kuske et al., “Basic Design Choices for the BESSY III MBA Lattice”, IPAC22, MOPOTK009
B.C. Kuske et al., “Further aspects of the deterministic lattice design app. for BESSY III”, IPAC23, WEPL039
P. Goslawski et al., “Update on the lattice design process of BESSY III: towards a baseline lattice”, IPAC23, WEPL036

Robust Design & TRIBs:

J. Bengtsson et al., “Robust Design and Control of the Nonlinear Dyn. for BESSY-III”, IPAC21, MOPAB048
M. Arlandoo et al., “A First attempt at implem. TRIBs in BESSY III’s Design Lattice”, IPAC21, THPOPT003
J. Bengtsson et al., “Robust design of modern Chasman-Green lattices - a geometric control theory approach”, IPAC2023, WEPL037
M. Arlandoo et al., “Further investigations of TRIBs in BESSY III design MBA lattices

Overview:

P. Goslawski et al., “BESSY III & MLS II - Status of ..”, IPAC21, MOPAB126
P. Goslawski et al., “BESSY III Status Report and Lattice Design Process”, IPAC22, TIPOMS010
P. Goslawski et al., “BESSY III - status and overview”, IPAC23, MOPA174

The process towards a BESSY III lattice

Talk by B. Kuske, Tuesday
Deterministic approach to MBA lattice design

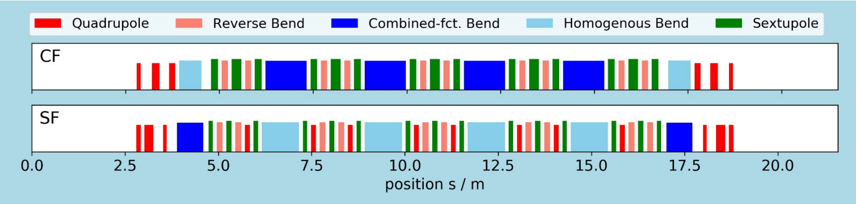
Talk by J. Völker on Thursday,
Sustainability at BESSY III

A deterministic lattice approach

- Stepwise: Power and Function of each Component &“Knob” → **LEGO approach**
- **Limiting the hardware** (conservative ansatz)
  Sustainability - permanent magnets
  - Bore diameter of 25 mm
    Diameter inner/outer vac. pipe of 18/21 mm
  - Bends up to 1.4 T
  - Combined fct. Bend 0.8 T & 15 T/m or 30 T/m
  - Quads up to 60 - 80 T/m (depends on RB)
  - Sextupoles up to 4000 T/m²
  - Spacing between magnets 100 mm
- **H**igher**O**rder**A**chromat Approach:
  - 6MBA + **homogenous metrology bend**

Two lattice candidates

- Different hardware solutions:
  - **cf**-lattice: combined function bend
    In center of 6MBA (community standard)
    sf - **cf - cf - cf - cf** - sf
    cf - **cf - cf - cf - cf** - cf
  - **sf**-lattice: separated (homogenous)
    Bend in the center of 6MBA (metrology):
    cf - **sf - sf - sf - sf** - cf
    sf - **sf - sf - sf - sf** - sf
- PTB needs a metrology bend, one would be enough



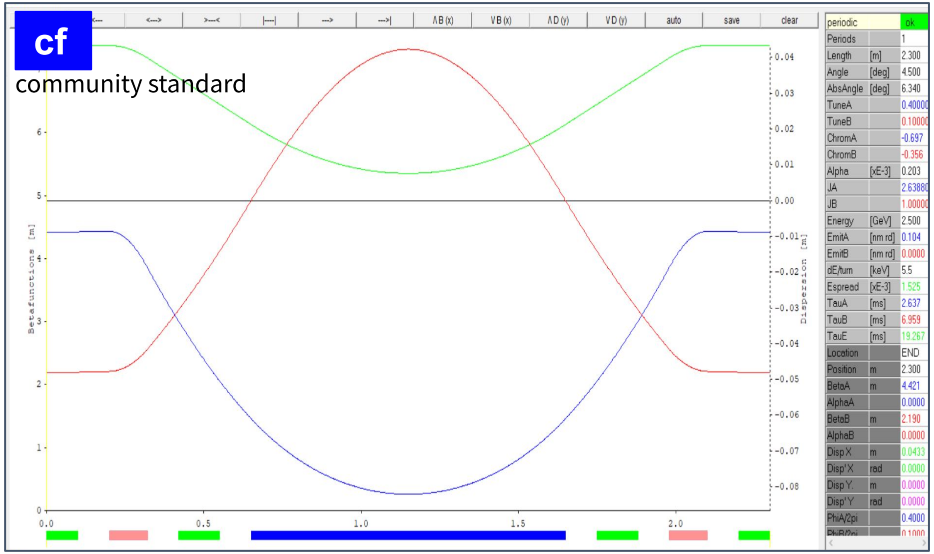
Linear Beam Dynamics

LEGO approach - the "one and only" (deterministic) MBA-Unit Cell (UC) for and for the hardware specifications of our project

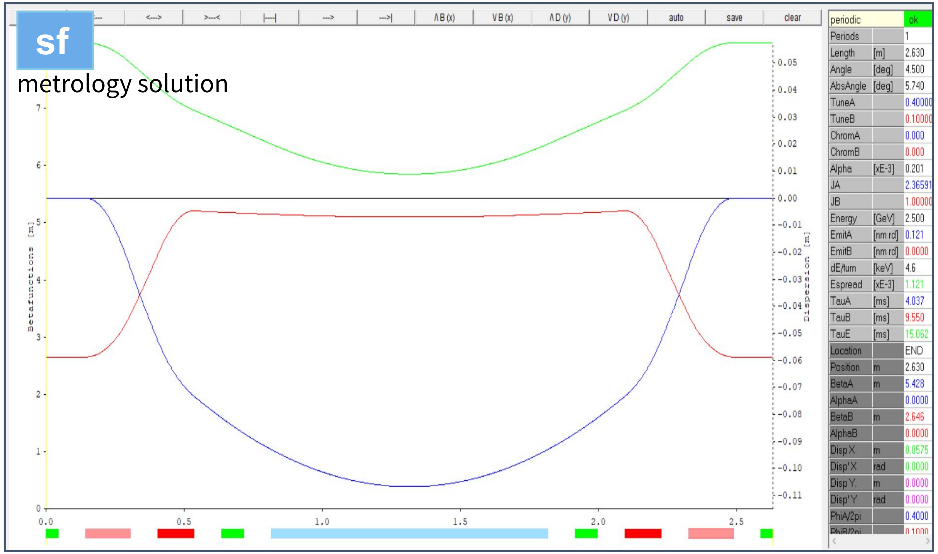
- The two different MBA-UCs: **cf & sf**
- UC (4.5°): Q_xy = (0.4, 0.1), Chrom_xy = (0.0, 0.0)

Impact of reverse bend on alpha & emittance

Magnet arrangement



SX, RB, SY, B, …



SX, RB, QD, SY, B, …

A. Streun, NIM-A, 737 (2014), 148-154
The anti-bend cell for ultralow emittance storage ring lattices

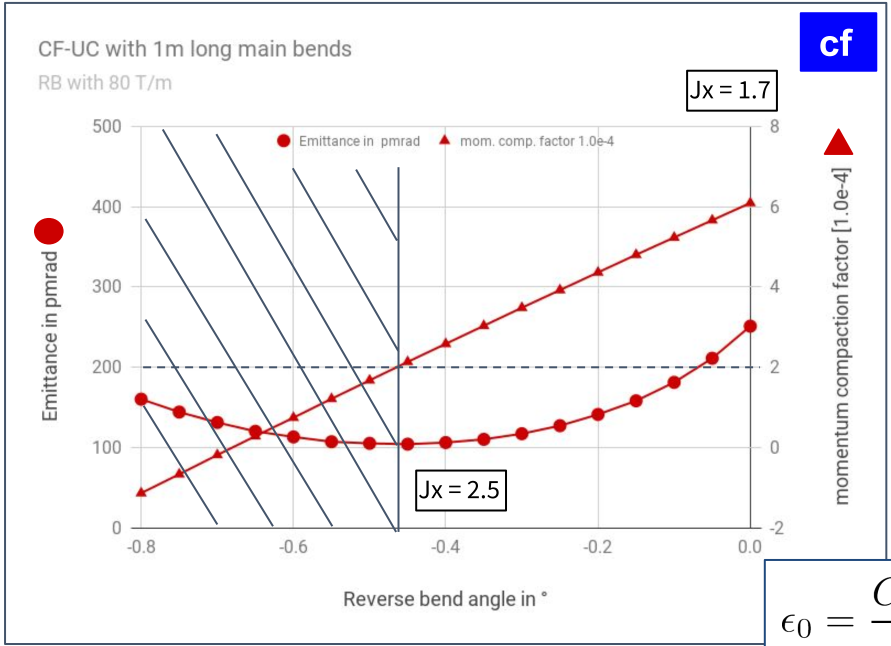
Linear Beam Dynamics

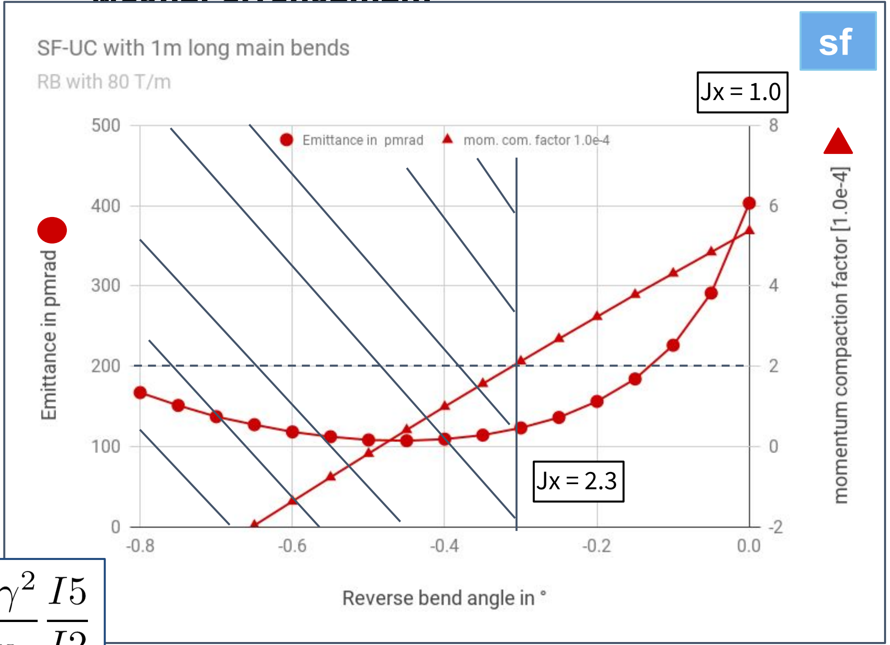
LEGO approach - Unit Cell - Impact of Reverse Bend

- The two different MBA-UCs: **cf & sf** and for the hardware specifications of our project
- UC (4.5°): Q_xy = (0.4, 0.1), Chrom_xy = (0.0, 0.0)

Impact of reverse bend on alpha & emittance

Magnet arrangement





$$\epsilon_0 = \frac{C_q \gamma^2}{j_X} \frac{I5}{I2}$$

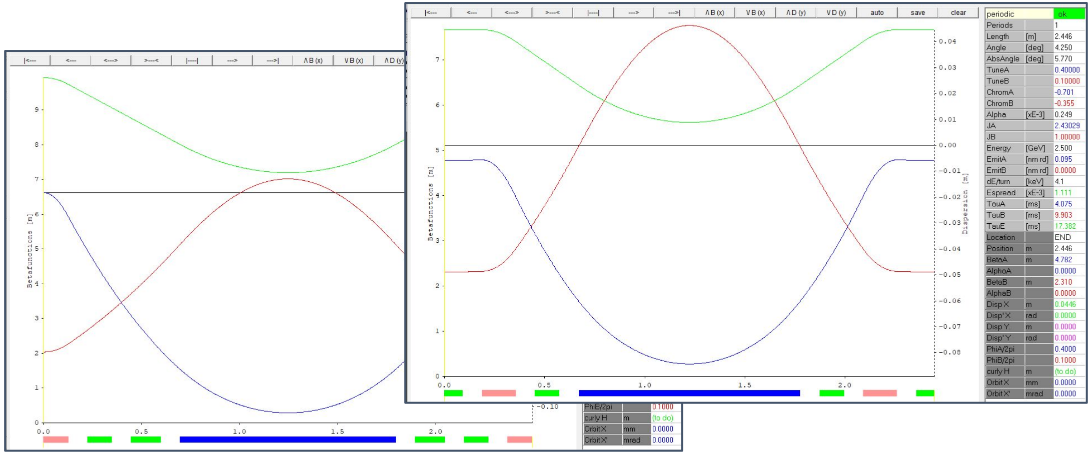
Linear Beam Dynamics

LEGO approach - Unit Cell - Magnet arrangement

- How to set up the MBA-UC ?
- Magnet positioning/arrangement in that way, to reduce the sextupole strength for the chromatic correction → as less as possible non-linear power

$$\xi_{tot} \sim \oint [k_2(s)\ D(s) - k_1(s)]\ \beta(s)\ ds$$

- **The cf MBA-UC:**



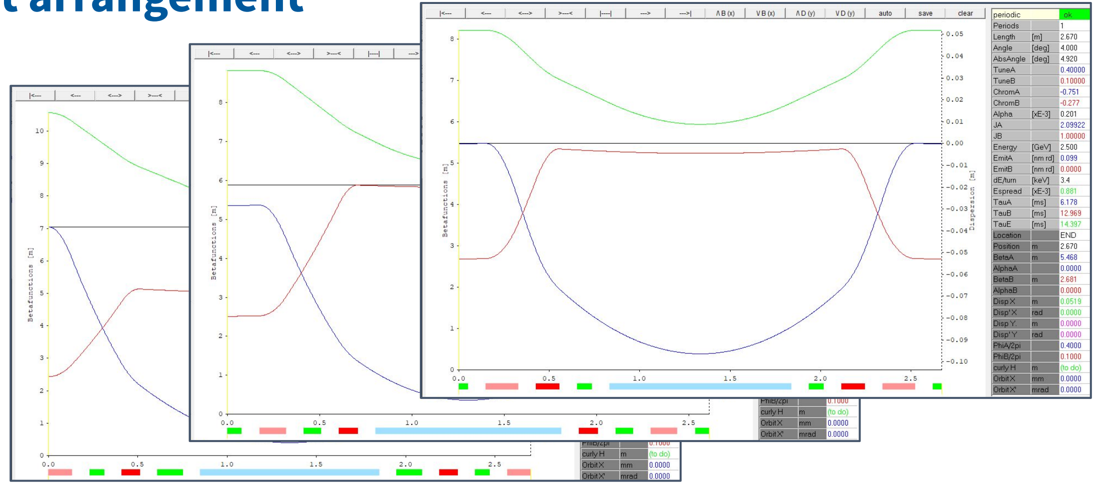
SetUp	Length	alpha	Emittance	RB angle	Nat Chrom	SUM(b3 * L)² for Chrom = 0 SF, SD [1/m²]
SX, RB, SY, B	2.446 m	2.5e-4	95 pm rad	-0.38 ° (k = 6.7) L = 0.163*2	-0.701, -0.355	**2324.77** 21.02, -26.84
RB, SX, SY, B	2.490 m	2.7e-4	95 pm rad	-0.26° (k = 6.8) L = 0.125 *2	-0.802, -0.278	**3905.21** 27.96, -34.22

Linear Beam Dynamics

sf

LEGO approach - Unit Cell - Magnet arrangement

- How to set up the MBA-UC ?
- Magnet positioning/arrangement in that way, to reduce the sextupole strength for the chromatic correction
  → as less as possible non-linear power



$$\xi_{tot} \sim \oint [k_2(s)\ D(s) - k_1(s)]\ \beta(s)\ ds$$

- **The sf MBA-UC:**

SetUp	Length	alpha	Emittance	RB angle	Nat Chrom	SUM(b3 * L)² for Chrom = 0 SF, SD [1/m²]
SX, RB, QD, SY, B	2.670 m	2.0e-4	100 pm rad	-0.23 ° (k = 8.6) L = 0.175*2	-0.751, -0.277	**901.43** 10.56, -18.42
SX, RB, SY, QD, B	2.610 m	2.1e-4	98 pm rad	-0.23° (k = 8.5) L = 0.14 * 2	-0.740, -0.295	**1500.19** 17.60, -20.98
RB, SX, QD, SY, B	2.700 m	2.0e-4	98 pm rad	-0.19° (k = 8.4) L = 0.13 * 2	-0.835, -0.232	**2781.58** 19.39, -31.86

Linear Beam Dynamics

LEGO approach - Unit Cell -

- The two different MBA-UCs: **cf & sf**
- UC (4.5°): Q_xy = (0.4, 0.1), Chrom_xy = (0.0, 0.0)

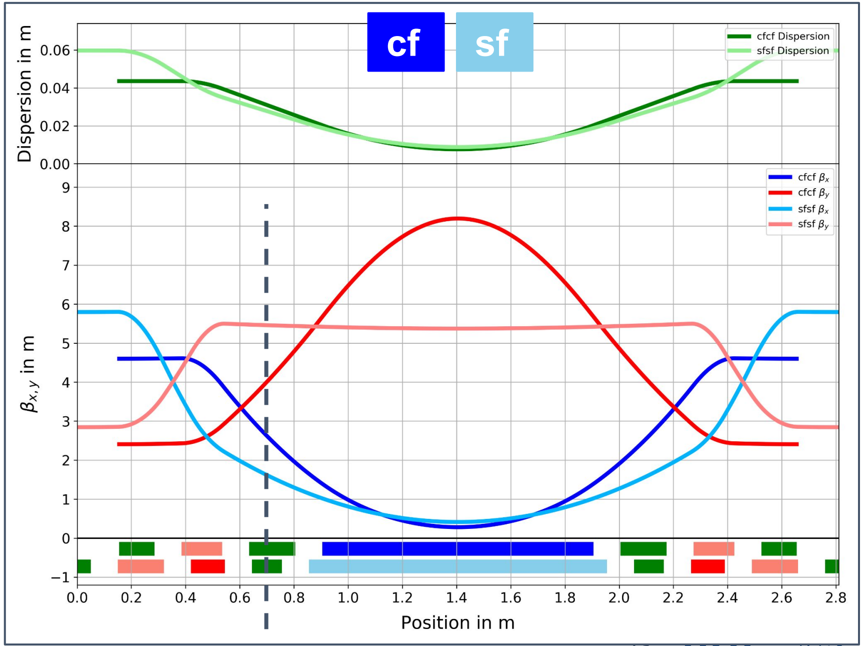
$$\xi = \frac{\Delta Q}{\Delta p/p} \sim \oint -k_1(s)\beta(s)ds$$

$$\xi_{tot} \sim \oint [k_2(s)\ D(s) - k_1(s)]\ \beta(s)\ ds$$

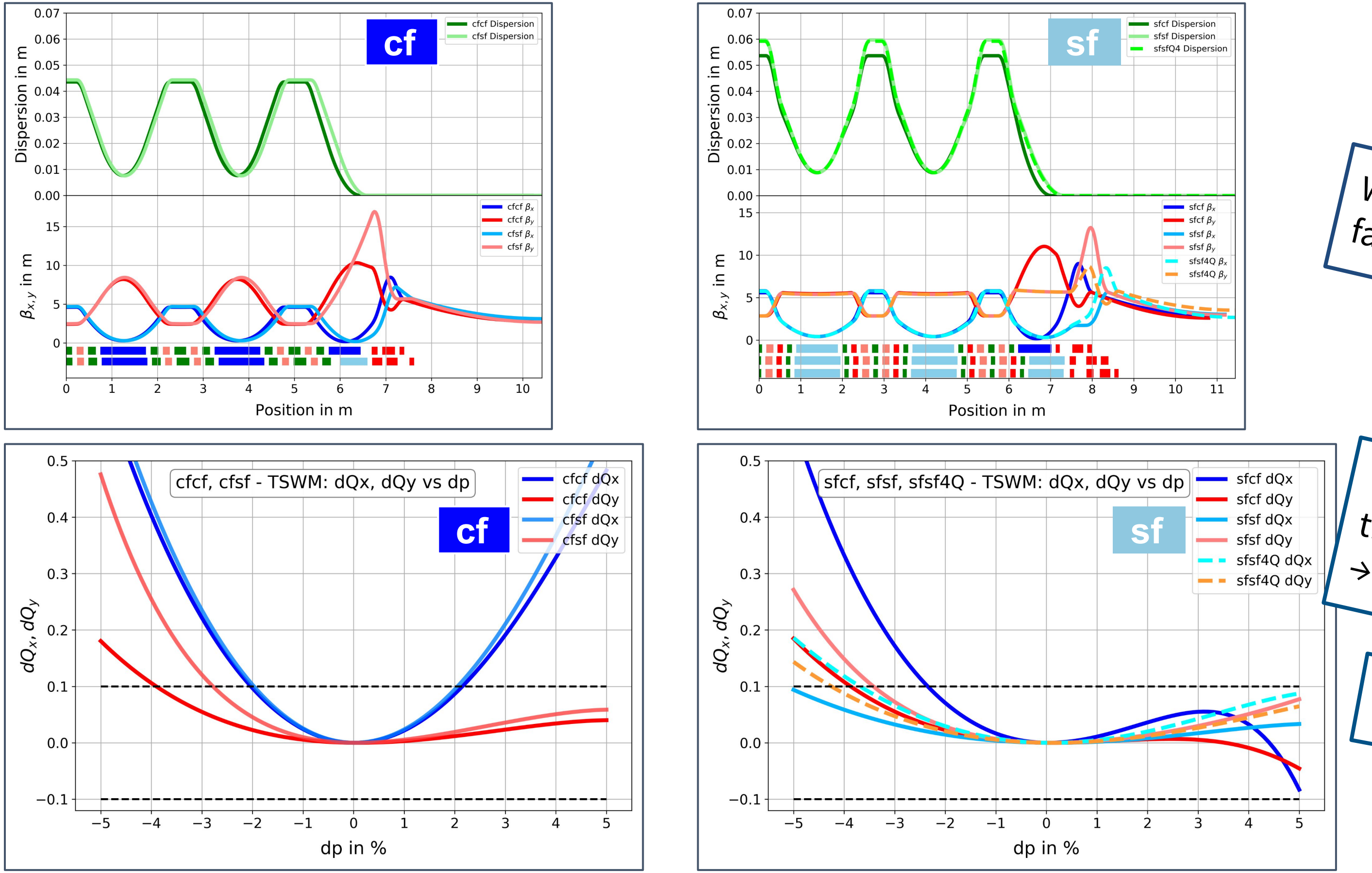
and for the hardware specifications of our project

Impact of reverse bend on alpha & emittance

Magnet arrangement



Non-Linear Beam Dynamics - TSWM, Chromatic Tune Shift

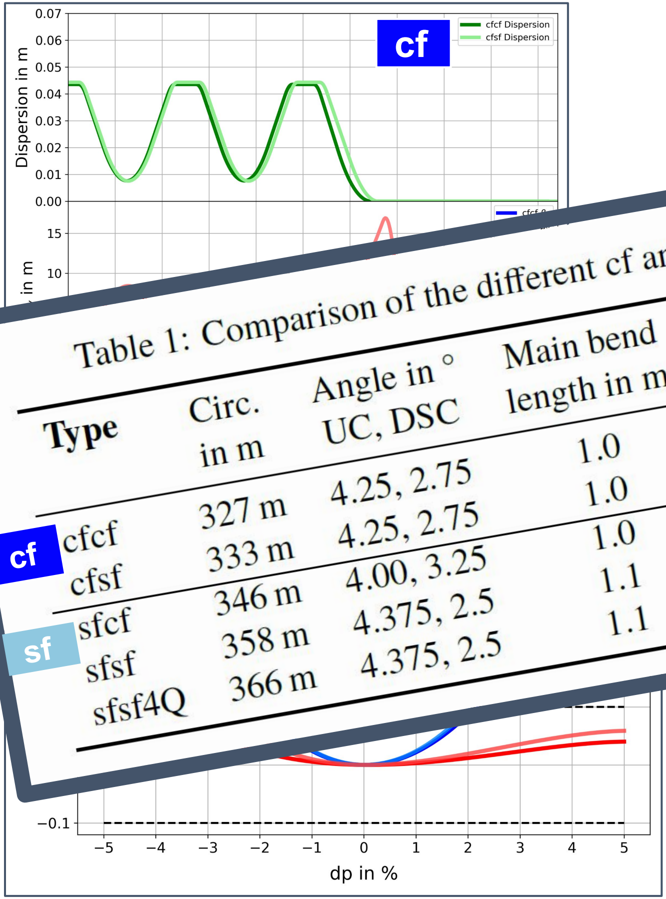


With two sextupole families only: Sx, Sy

The flatter the curve the better
→ Robustness, Lifetime

$$\frac{1}{\tau_t} = \frac{N r_e^2 c}{8\pi} \frac{1}{\sigma_x \sigma_y \sigma_s} \frac{1}{\gamma^2 \delta_{acc}^3} D(\zeta)$$

Non-Linear Beam Dynamics - TSWM, Chromatic Tune Shift



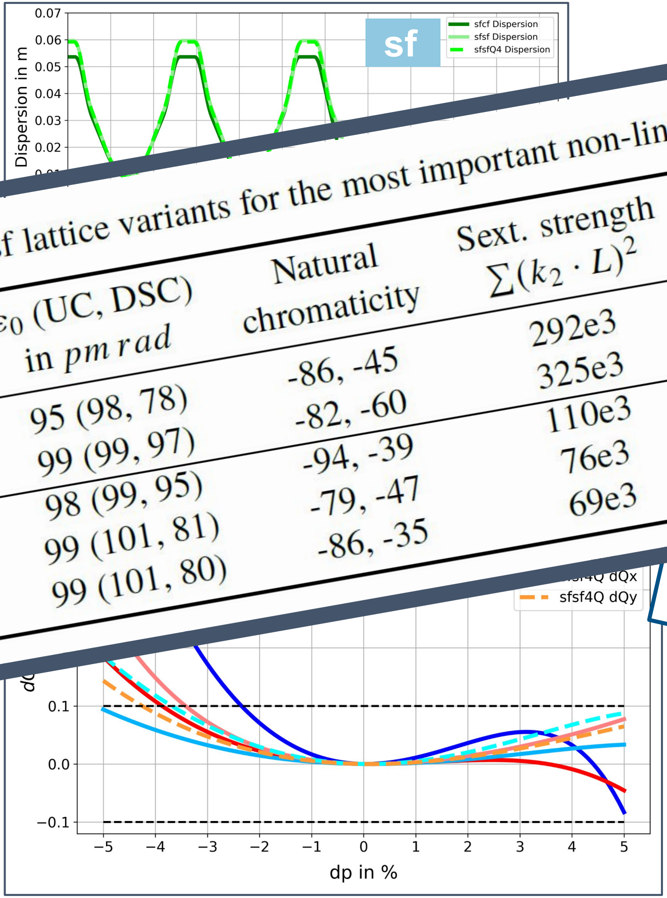


Table 1: Comparison of the different cf and sf lattice variants for the most important non-linear parameters.

	Type	Circ. in m	Angle in ° UC, DSC	Main bend length in m	ε_0 (UC, DSC) in $pm\,rad$	Natural chromaticity	Sext. strength $\sum(k_2 \cdot L)^2$	TSWM, dp in % for $dQ_{x,y} = 0.1$
cf	cfcf	327 m	4.25, 2.75	1.0	95 (98, 78)	-86, -45	292e3	2.0, 3.9
	cfsf	333 m	4.25, 2.75	1.0	99 (99, 97)	-82, -60	325e3	2.1, 2.8
sf	sfcf	346 m	4.00, 3.25	1.0	98 (99, 95)	-94, -39	110e3	2.3, 3.9
	sfsf	358 m	4.375, 2.5	1.1	99 (101, 81)	-79, -47	76e3	5.0, 3.4
	sfsf4Q	366 m	4.375, 2.5	1.1	99 (101, 80)	-86, -35	69e3	3.8, 4.3

…the curve
…e better
→ Robustness, Lifetime

$$\frac{1}{\tau_t} = \frac{N r_e^2 c}{8\pi} \frac{1}{\sigma_x \sigma_y \sigma_s} \frac{1}{\gamma^2 \delta_{acc}^3} D(\zeta)$$

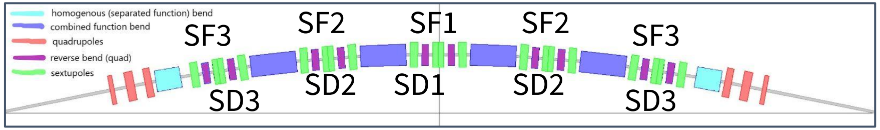
Non-Linear Beam Dynamics - Sextupole Split Up

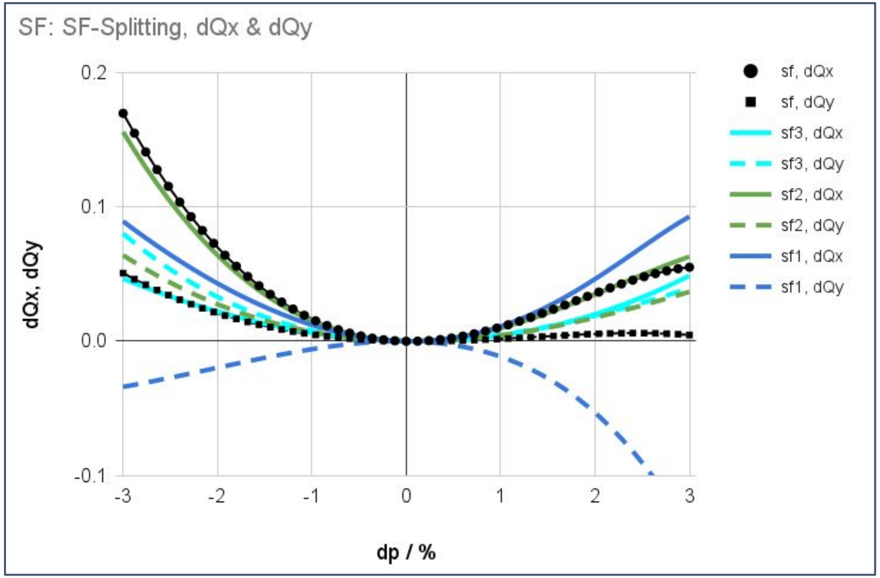
Non-linear optimization

In progress

with S.A. Garcia from KIT and AI

- Defining target parameters for non-linear optimization and "knobs"
- **Target parameters:** (benchmark MAX IV, SLS2):
  - Tune Shift With Momentum **TSWM:**
    ΔQx, ΔQy ~ 0.1 at Δp = +-3% (+-5%)
  - Tune Shift with Amplitude **TSWA:**
    ΔQx, ΔQy ~ 0.1 limits acceptance ~3mm
- **Knobs:**
  - Chromatic Octupoles for 2nd order chromaticity
  - Split up of chromatic sextupoles (TSWM + TSWA)
- **Findings, Results:**
  - The two lattice candidates show an opposite behavior in order to reduce TSWM
    - SF3 with biggest impact at sf lattice
    - SF1 with biggest impact at cf lattice

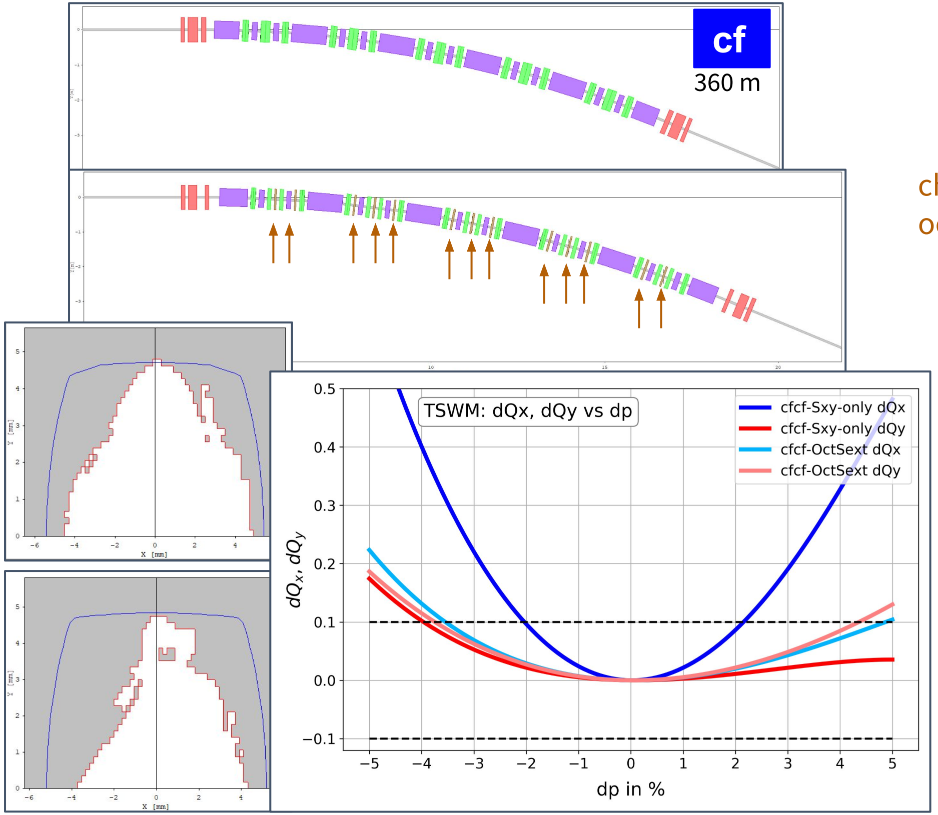




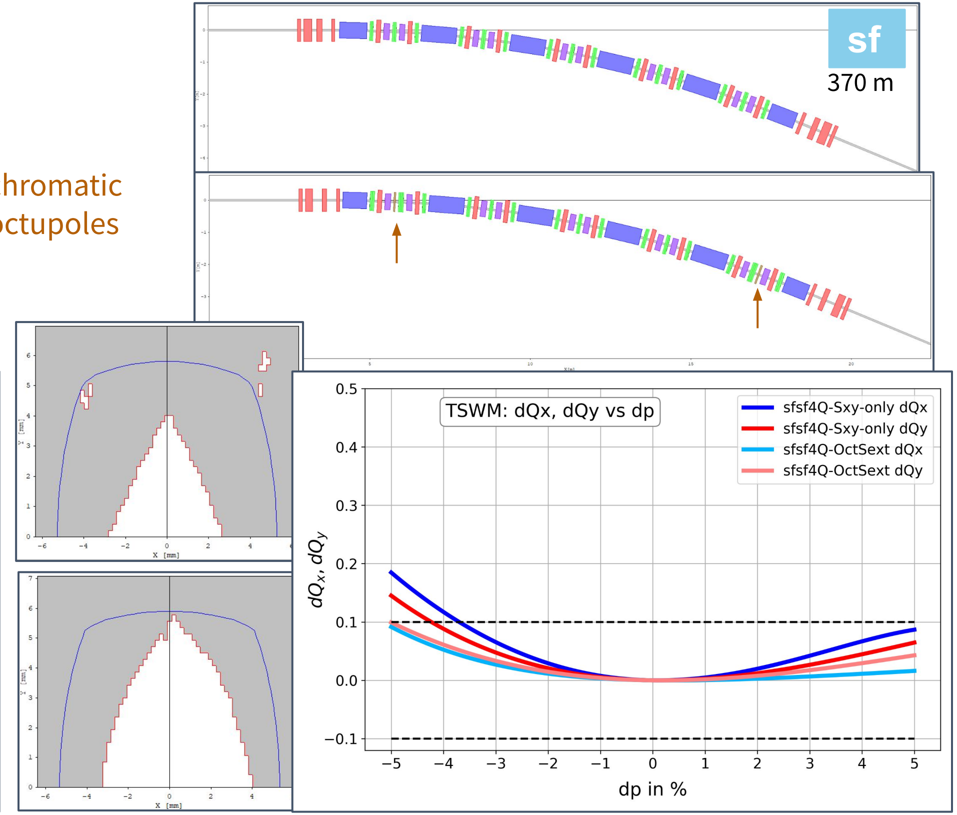
Non-Linear Beam Dynamics - Sextupole Split Up

In progress

Non-linear optimization



chromatic octupoles



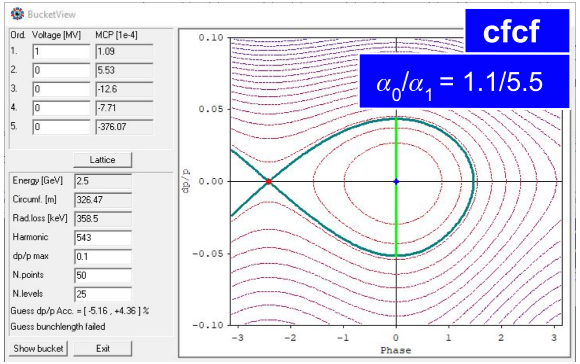
Alpha buckets - higher order of mom.com

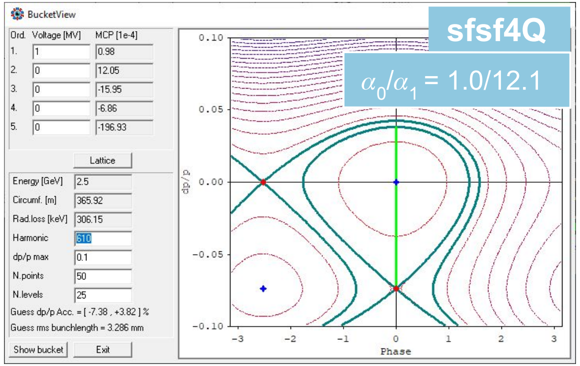
Thanks to A.Streun

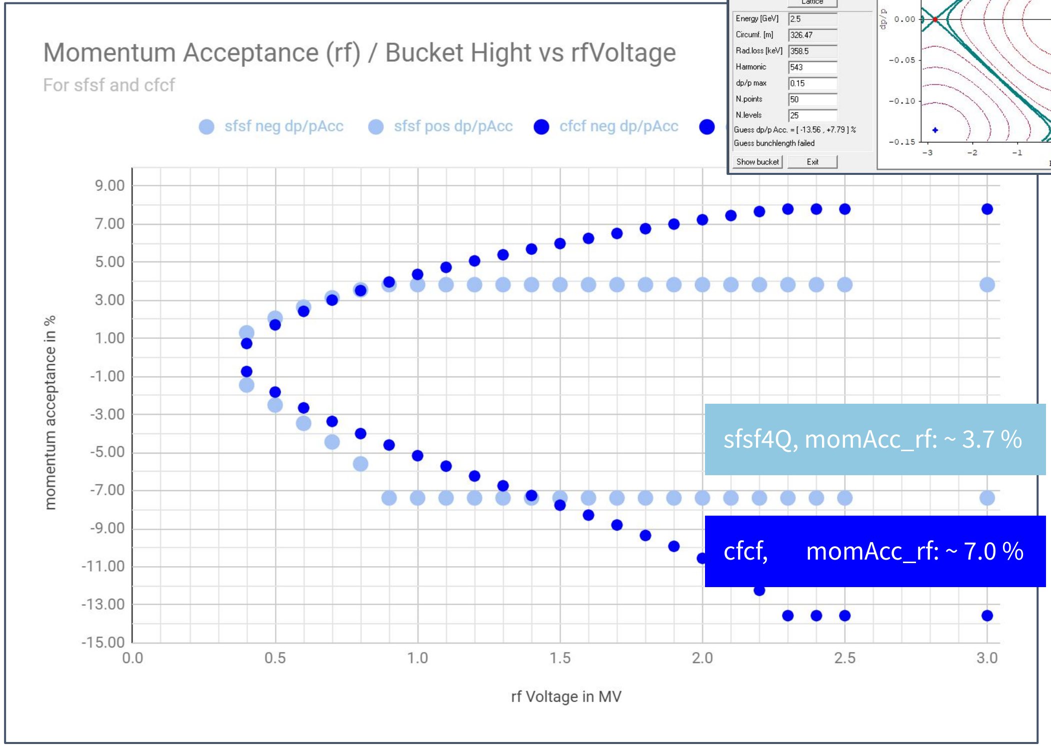
In progress

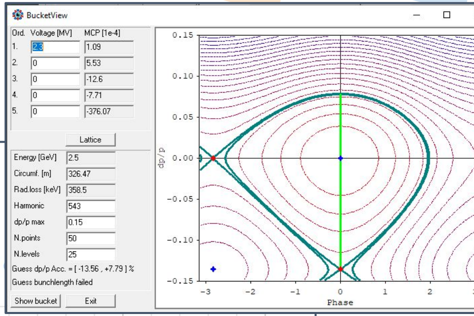
Limiting the momentum acceptance in the longitudinal plane

- cfcf, sfsf4Q









Alpha buckets - higher order of mom.com

In progress

Mismatch in momentum acceptance between longitudinal and transverse plane

Lattice variants	Mom.Acc. transverse plane $\delta_{acc,\ x,y}$ Chromatic Tune Shift TSWM, $Q_{x,y} = Q_{x,y}(\delta)$	Mom.Acc. longit. plane $\delta_{acc,\ rf}$ rf Acceptance	Alpha buckets Ratio between α_0/α_1
cfcf	2% → 3%	8%	1.1 / 5.5
sfsf4Q	4% → 5%	~ 4%	1.0 / 12.1

D. Robin, E. Forest et al., "Quasi-isochronous storage rings", Phys. Rev. E **48**, 2149, (1993)

- The often forgotten longitudinal plane …
  - Three oscillators in x, y, delta with three natural chromaticities, but only two sextupolesfamilies for correction
  - α_1 is the 2nd order path lengthening is the longitudinal chromaticity
  - Ratio of α_0/α_1 defines the alpha bucket (unstable off-momentum fix point), and starts to limit the rf momentum acceptance

$$x = x_\beta + D\,\delta + D_1\,\delta^2$$

$$\Delta L/L_0 = \alpha(\delta)\,\delta = \alpha_0\,\delta + \alpha_1\,\delta^2 + \ldots$$

$$\alpha_0 = \frac{1}{L_0}\oint \frac{D}{\rho}\,ds \qquad \alpha_1 = \frac{1}{L_0}\oint \frac{D'^2}{2} + \frac{D_1}{\rho}\,ds$$

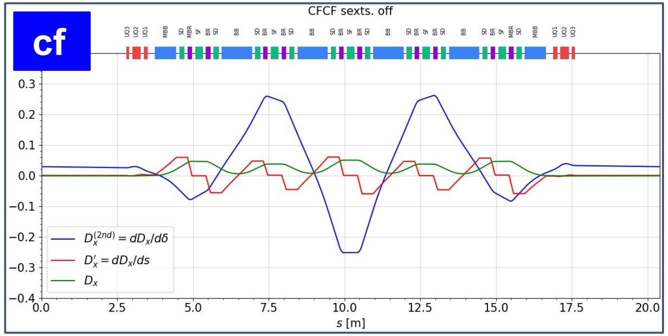
Alpha buckets - higher order of mom.com

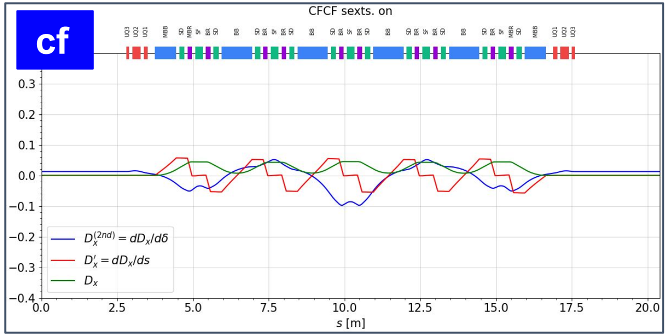
In progress
Michael Arlandoo

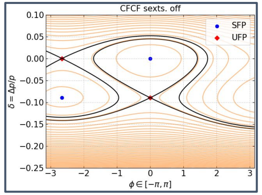
Natural Chromaticity in long. plane & Knobs for Correction (or Attack)

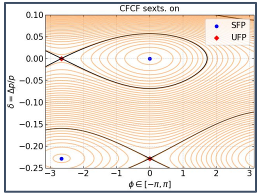
- Ratio of α_0/α_1 limits the rf momentum acceptance
- Increase α_0, reduce RB &/or lengthen main bend
- Reduce α_1, figure out what is the biggest contribution

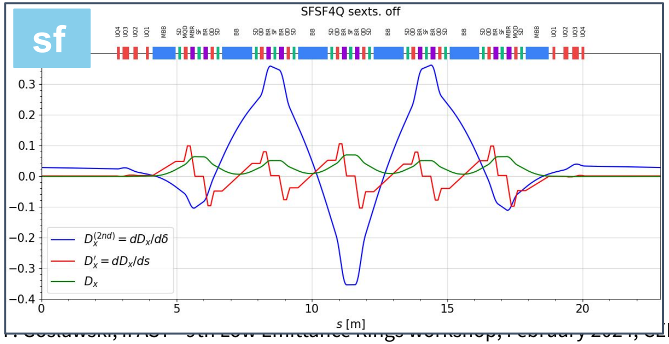
$$\alpha_0 = \frac{1}{L_0} \oint \frac{D}{\rho}\, ds \qquad \alpha_1 = \frac{1}{L_0} \oint \frac{D'^2}{2} + \frac{D_1}{\rho}\, ds$$

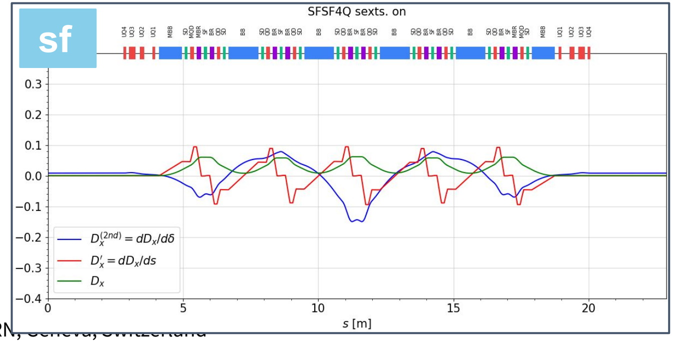












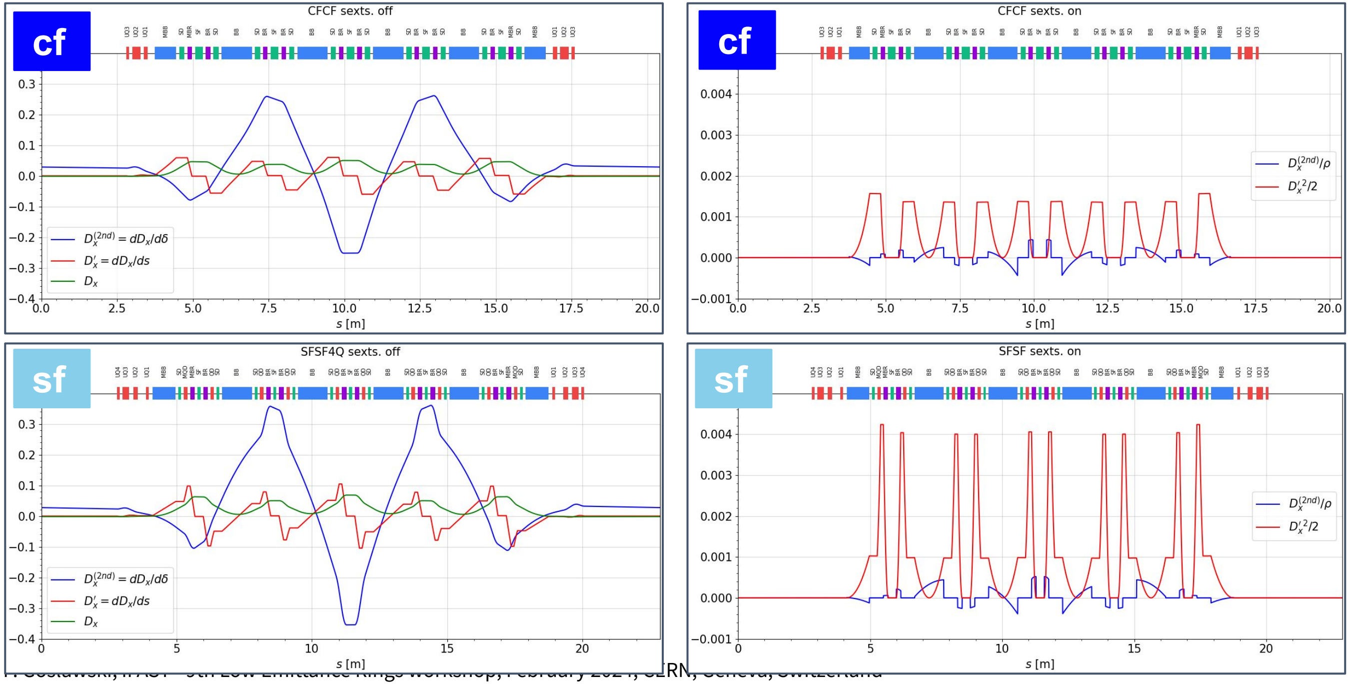
Alpha buckets - higher order of mom.com

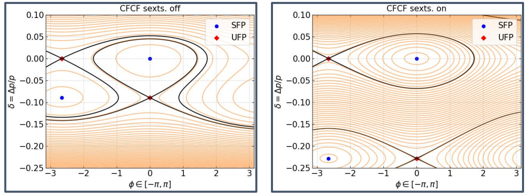
In progress
Michael Arlandoo

Natural Chromaticity in long. plane & Knobs for Correction (or Attack)

- Ratio of α_0/α_1 limits the rf momentum acceptance
- Increase α_0, reduce RB &/or lengthen main bend
- Reduce α_1, figure out what is the biggest contribution

$$\alpha_0 = \frac{1}{L_0}\oint \frac{D}{\rho}\, ds \qquad \alpha_1 = \frac{1}{L_0}\oint \frac{D'^2}{2} + \frac{D_1}{\rho}\, ds$$





The sf-UC with the additional vertical focussing quadrupole with very good separation of beta_xy functions at the chromatic sextupoles which guarantees for good TSWM,

generates small mom. Acc. in the longitudinal plane

Alpha buckets - higher order of mom.com

Natural Chromaticity in long. plane & Knobs for Correction (or Attack)

- Ratio of α_0/α_1 limits the rf momentum acceptance
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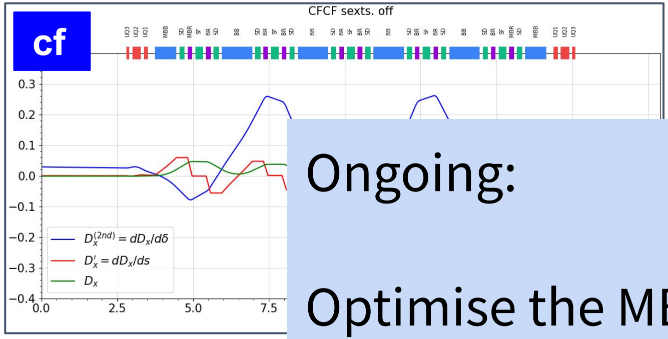
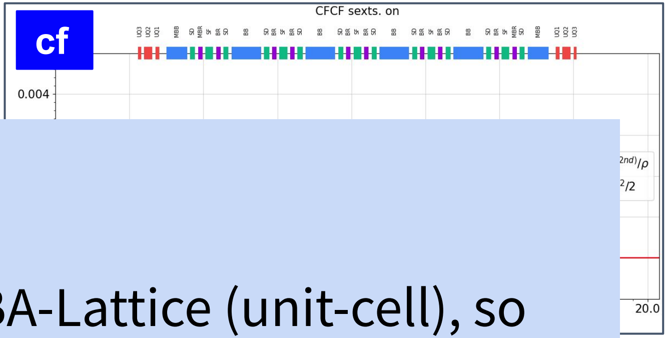
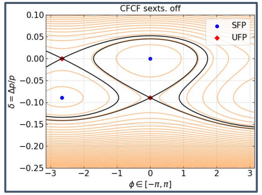
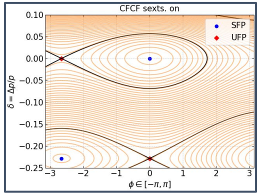


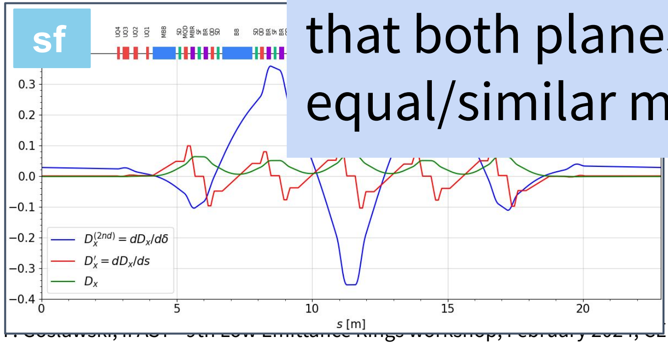


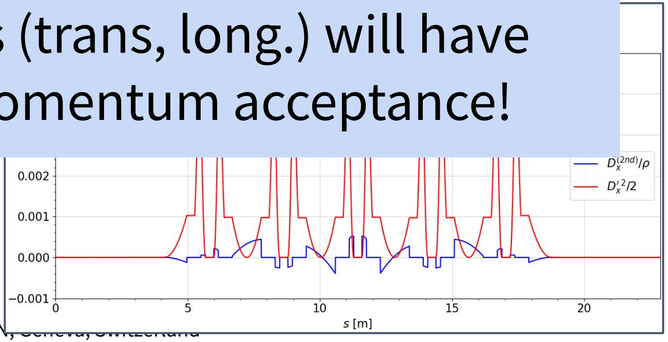




Ongoing:

Optimise the MBA-Lattice (unit-cell), so that both planes (trans, long.) will have equal/similar momentum acceptance!





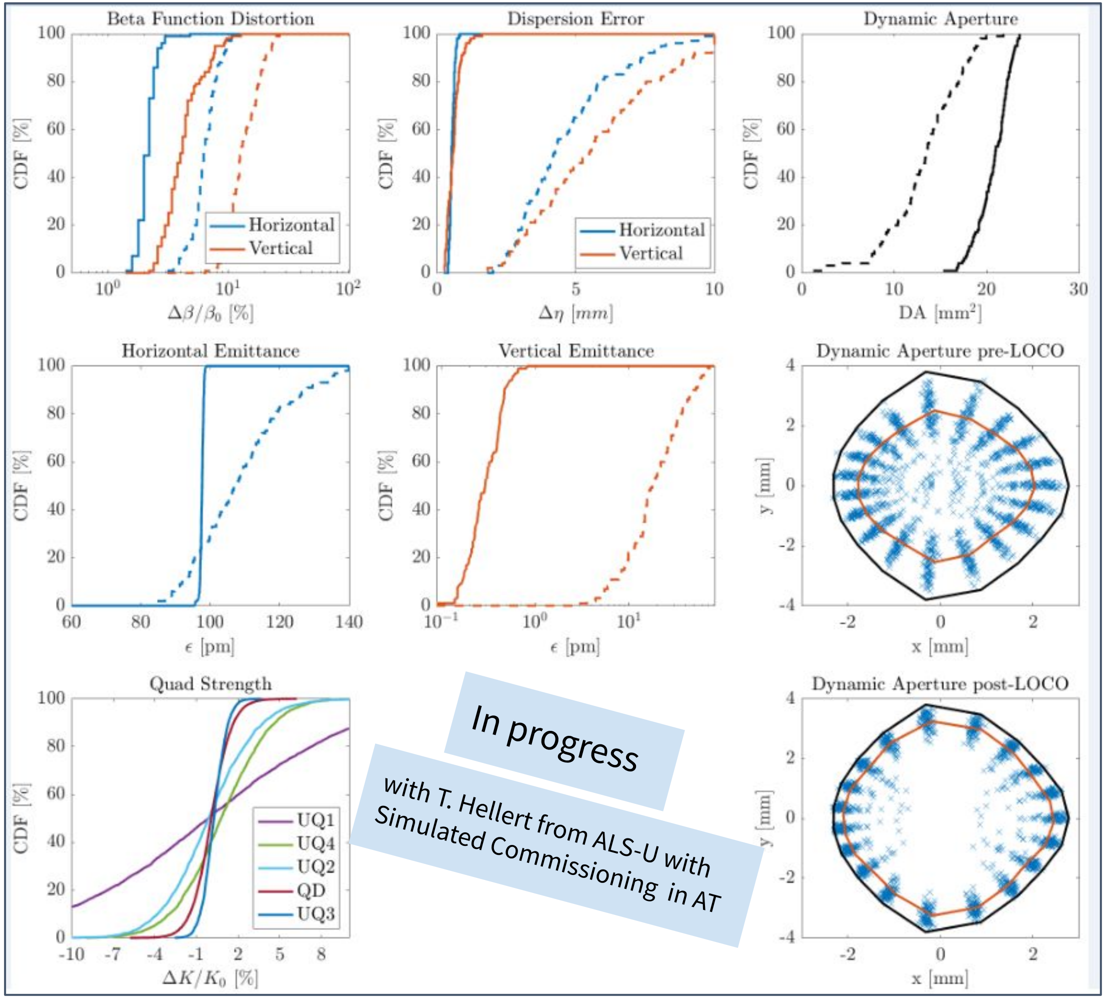
The sf-UC with the additional vertical focussing quadrupole with very good separation of beta_xy functions at the chromatic sextupoles which guarantees for good TSWM,

generates small mom. Acc. in the longitudinal plane

The process towards a BESSY III lattice

Robustness Analysis & Simulated Commissioning

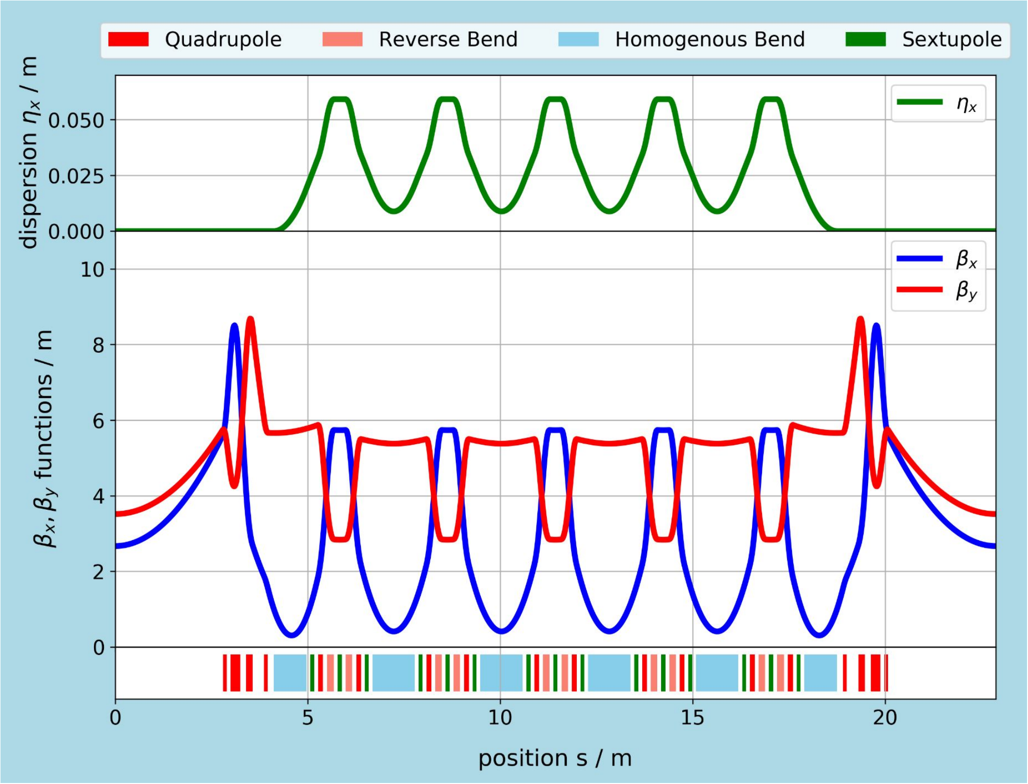
- J. Bengtsson with tracy or thor_scsi
  - Robustness analysis against misalignments and magnet field uncertainties (errors), HOA, Phase Advance, Periodicity
  - Conclusion: Two stable and robust solutions cfcf, sfsf4Q with ~ 3%, 5% momentum acceptance
- T. Hellert with AT and Simulated Commissioning
  - BBA, Correct Orbit, LOCO



The process towards a BESSY III lattice - Summary

LEGO approach - the UC

- Two robust solutions: cfcf, sfsf4Q
  - cfcf: less magnets, little bit shorter, but mom.acc_xy only ~2-3%
  - sfsf4Q: more magnets, strongly reduced sextupole strength for chromaticity correction, mom.acc_xy ~4-5%
  - **Matching with longitudinal plane!**
- Currently ongoing / Next steps:
  - Non-linear optimisation scheme
  - Robustness & Tolerance analysis
  - Injection scheme & Collective effects
  - **Intensify discussions with construction & engineering department**



Thank you for your attention !

Backup Slides

Overview - BESSY II+ / III

Towards BESSY III by using BESSY II, BESSY II+

BESSY II+ paves the way to BESSY III

BESSY II+

	BESSY II+ project					Operation								
2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036

Beamline Transfer

BESSY III

CDR			TDR				Project/Construction						Com.	Operation	
2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	...

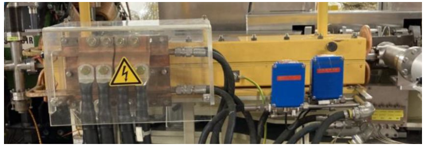
BESSY II+ application/project: operando capabilities, modernization, and sustainability.

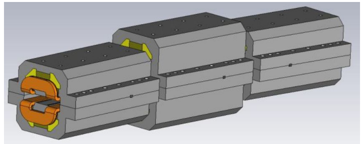
100 M€ (25 % HZB, 25% strategic partners or third-party projects, 50 % request funding bodies) split up in

- 50 % for 8 new beamlines, endstations & sample environment, → Future BESSY III Science Case
- 15 % for improving the sustainability of BESSY II, → BESSY III Hardware / Tech.
- 35 % modernization of the accelerator complex

Active Higher-Harmonic Cavities together with ALBA & DESY – first beam test in BESSY II now !

Hybrid-Permanent Magnets
– replace power hungry (30 kW) bending electromagnet in BESSY II transferline
– metrology suitable PM dipole





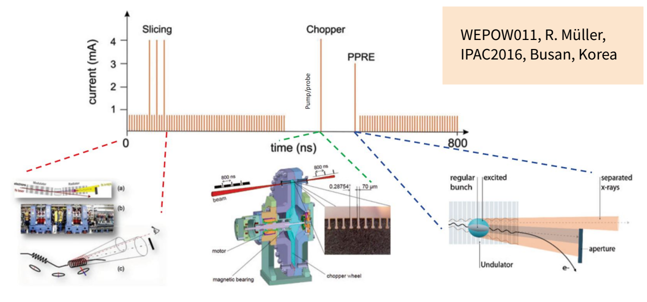
BESSY II Specialties

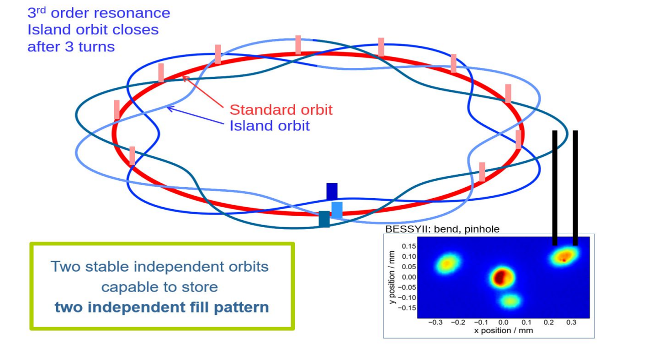
HZB Helmholtz Zentrum Berlin

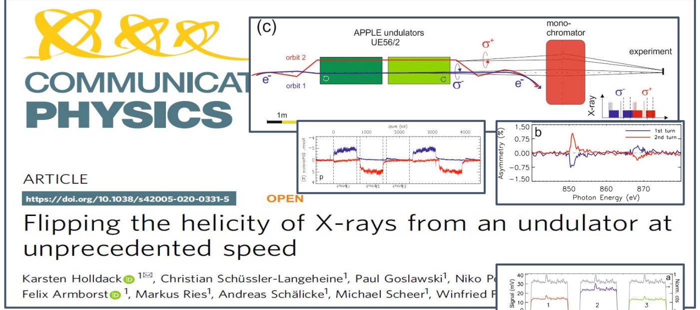
BESSY II

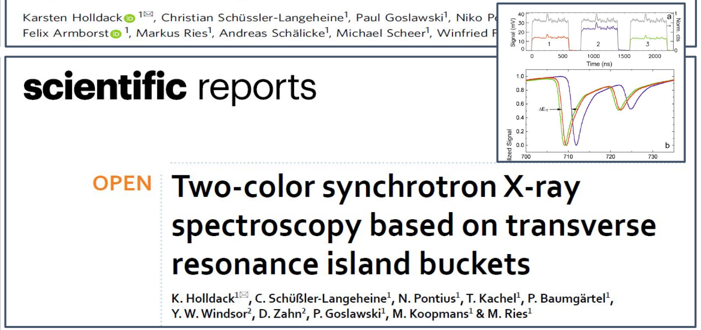
1.7 GeV, DBA,
5 nm rad, 300 mA
240 m, 16 Straights, 5 m
since 1998

Soft and tender X-rays
Spectro-Microscopy
Timing: low α, femto-slicing
SB, VSR, TRIBs/2-Orbits









2 PhD Thesis

2022-02-03 Dissertation DOI: 10.18452/23851
Transverse Resonance Island Buckets at BESSY II
A new Bunch Separation Scheme
Armborst, Felix

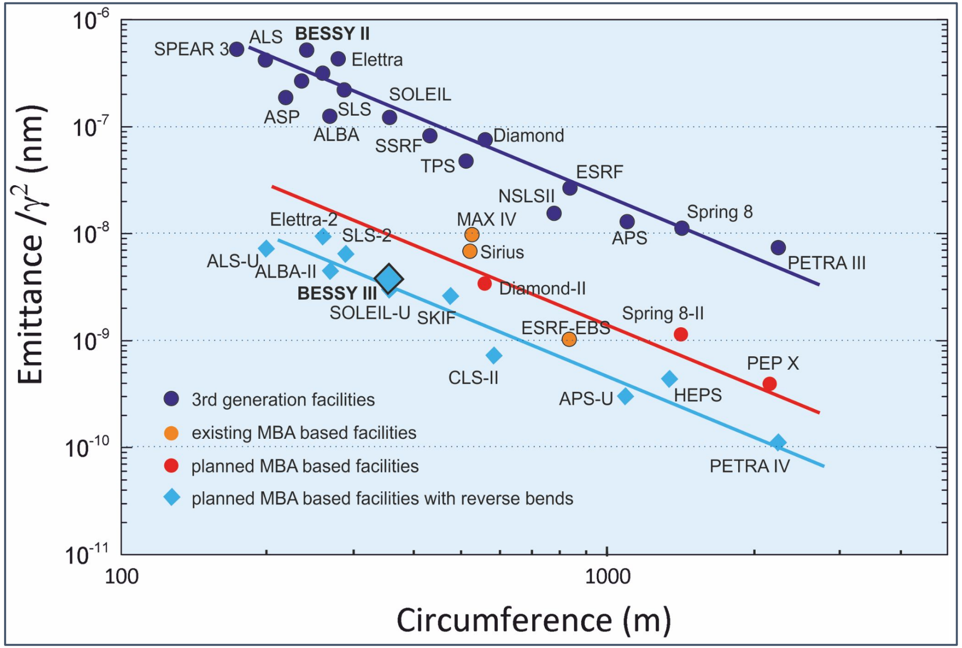
Transverse Resonance Island Buckets in Advanced Light Sources
Arlandoo, Michael

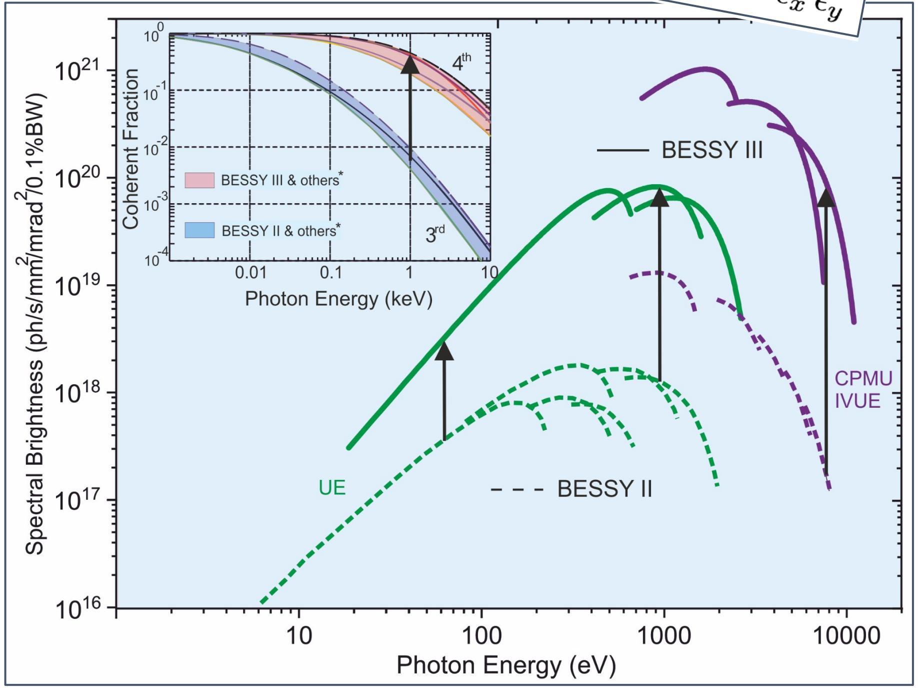
Solar Energy	Chemical Energy	Quantum & Functional Materials
Photon Science	Accelerators	Scientific Instrumentation & Support

BESSY III

100x times more brightness than BESSY II &
1000x times smaller focus at sample (10µm down to 10nm)

$$B(\lambda) = \frac{F(\lambda)}{4\pi^2\,\epsilon_x\,\epsilon_y}$$



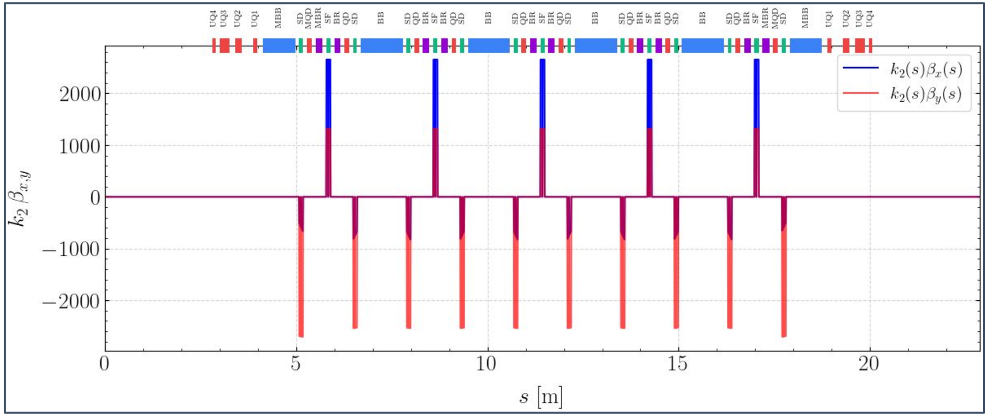


In situ & operando, sample environment, material & metrology labs → Integrated Research Campus

Higher Order Achromat

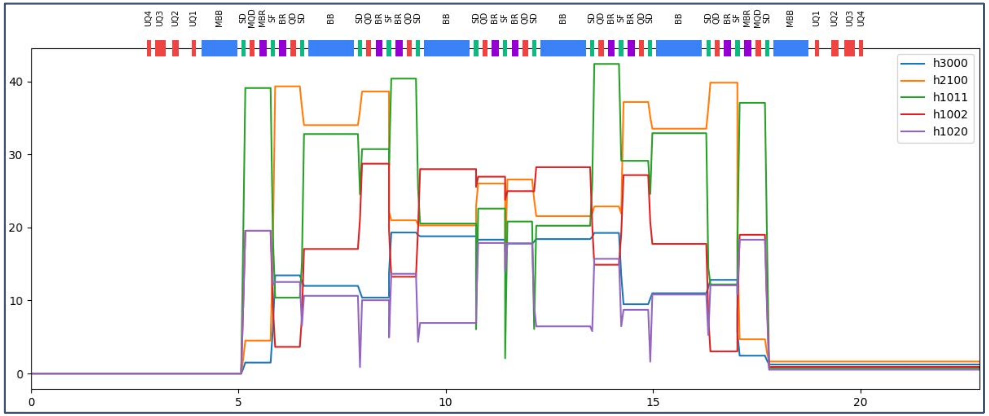
Periodicity of Sextupoles and Phase Advance between Sextupoles

- Geometric resonance driving terms cancel if the phase advance between sextupole cells is chosen wisely.
- …



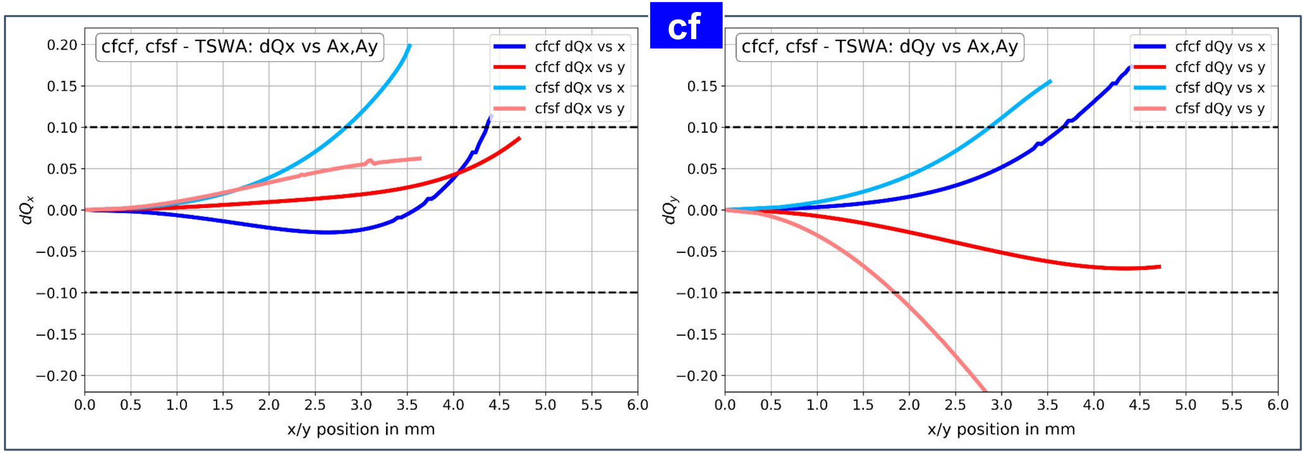
				First Order						Second Order				Third Order				
				Geometric				Chromatic		Geometric				Geometric				
Cell	ν_x	ν_y		ν_x	$3\nu_x$	ν_x-$2\nu_y$	ν_x+$2\nu_y$	$2\nu_x$	$2\nu_y$	$4\nu_x$	$4\nu_y$	$2\nu_x$-$2\nu_y$	$2\nu_x$+$2\nu_y$	$5\nu_x$	ν_x-$4\nu_y$	ν_x+$4\nu_y$	$3\nu_x$-$2\nu_y$	$3\nu_x$+$2\nu_y$
1	0.400	0.100	2/5, 0.5/5	0.40	1.20	0.20	0.60	0.80	0.20	1.60	0.40	0.60	1.00	2.00	0.00	0.80	1.00	1.40
2	0.800	0.200		0.80	2.40	0.40	1.20	1.60	0.40	3.20	0.80	1.20	2.00	4.00	0.00	1.60	2.00	2.80
3	1.200	0.300		1.20	3.60	0.60	1.80	2.40	0.60	4.80	1.20	1.80	3.00	6.00	0.00	2.40	3.00	4.20
4	1.600	0.400		1.60	4.80	0.80	2.40	3.20	0.80	6.40	1.60	2.40	4.00	8.00	0.00	3.20	4.00	5.60
5	2.000	0.500		2.00	6.00	1.00	3.00	4.00	1.00	8.00	2.00	3.00	5.00	10.00	0.00	4.00	5.00	7.00

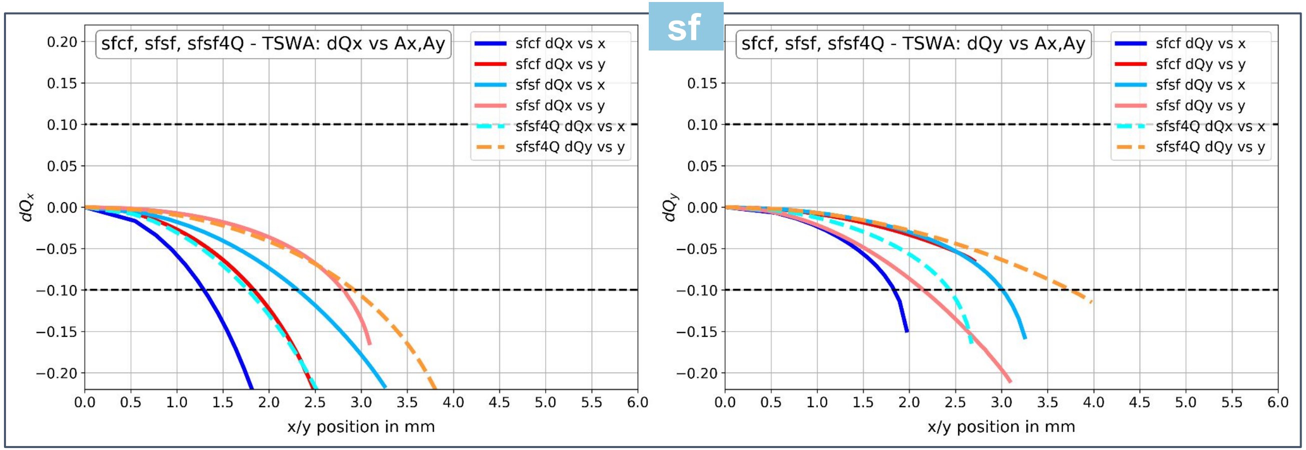
				Geometric				Chromatic		Geometric				Geometric				
Cell	ν_x	ν_y		ν_x	$3\nu_x$	ν_x-$2\nu_y$	ν_x+$2\nu_y$	$2\nu_x$	$2\nu_y$	$4\nu_x$	$4\nu_y$	$2\nu_x$-$2\nu_y$	$2\nu_x$+$2\nu_y$	$5\nu_x$	ν_x-$4\nu_y$	ν_x+$4\nu_y$	$3\nu_x$-$2\nu_y$	$3\nu_x$+$2\nu_y$
1	0.429	0.143	3/7, 1/7	0.43	1.29	0.14	0.71	0.86	0.29	1.71	0.57	0.57	1.14	2.14	-0.14	1.00	1.00	1.57
2	0.857	0.286		0.86	2.57	0.29	1.43	1.71	0.57	3.43	1.14	1.14	2.29	4.29	-0.29	2.00	2.00	3.14
3	1.286	0.429		1.29	3.86	0.43	2.14	2.57	0.86	5.14	1.71	1.71	3.43	6.43	-0.43	3.00	3.00	4.71
4	1.714	0.571		1.71	5.14	0.57	2.86	3.43	1.14	6.86	2.29	2.29	4.57	8.57	-0.57	4.00	4.00	6.29
5	2.143	0.714		2.14	6.43	0.71	3.57	4.29	1.43	8.57	2.86	2.86	5.71	10.71	-0.71	5.00	5.00	7.86
6	2.571	0.857		2.57	7.71	0.86	4.29	5.14	1.71	10.29	3.43	3.43	6.86	12.86	-0.86	6.00	6.00	9.43
7	3.000	1.000		3.00	9.00	1.00	5.00	6.00	2.00	12.00	4.00	4.00	8.00	15.00	-1.00	7.00	7.00	11.00



The process towards a BESSY III lattice - Non-Linear Beam Dynamics

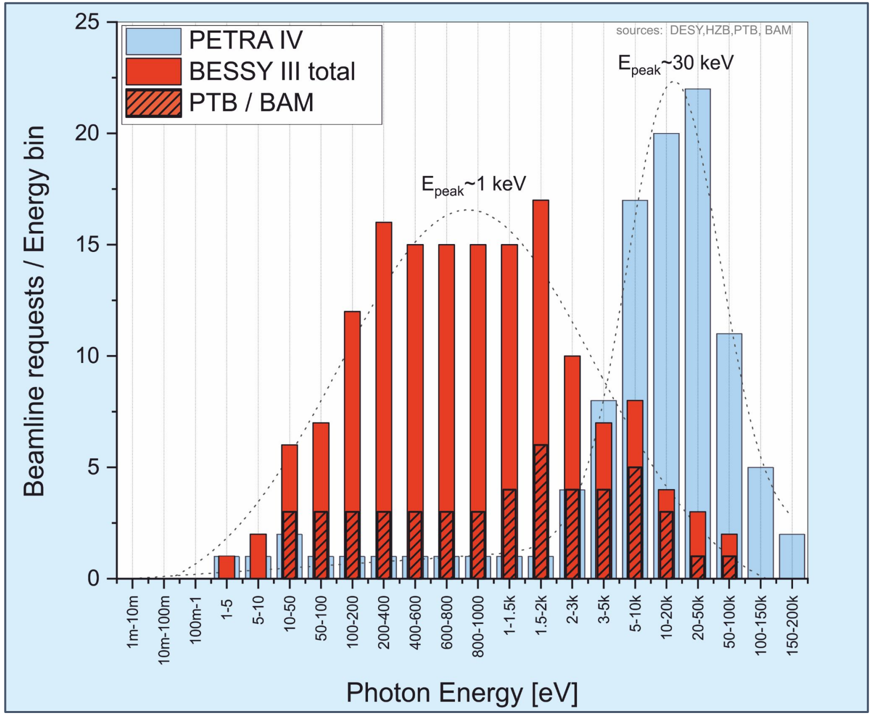
TSWA
Amplitude Dependent Tune Shift





BESSY III

Beamline Requests & Portfolio



#	Name	Photon Energy	Main Methods	Main Applications
1	VUV to Hard	5 eV - 20 keV	XPS, HAXPES, NEXAFS, STXM XPS, HAXPES, NEXAFS, STXM	Catalysis, Energy (Storage, Batteries, Solar Fuels)
	DIP	20 eV - 1.5 keV	UPS/XPS, NEXAFS, EXAFS, XPS, UPS, ARPES	Energy, Catalysis
2	Soft & Tender	100 eV - 4 keV	PES, HAXPES, TXM, XAS, XPCS Resonant Scattering, CDI	Energy (Batteries), Quantum Energy, Quantum
	DIP	2 - 14 keV	Diffraction/ EXAFS/XRF, NEXAFS,	Energy, Quantum, Catalysis
3	XUV to Soft	60 eV - 1.5 keV	BElChem, XPS BElChem, XPS	Catalysis, Chemistry Catalysis, Chemistry
	DIP	2 - 14 keV	XRD/ EXAFS, WAXS, SAXS, HAXPES	Energy, Catalysis
4	Magnetic Imaging	150 eV - 2 keV	Lensless Imaging, X-ray holography, XPCS STXM, Resonant Scattering, 3D mag. tomogr.	Quantum, Energy Quantum, Energy
	DIP	100 eV - 1.5 keV	XMCD, XAS with magnetic vector fields	Quantum, Energy
5	XUV Spectroscopy	5 - 200 eV	ARPES nano-ARPES	Quantum , Energy, Catalysis Quantum, Energy Catalysis
	DIP	80 eV - 4 keV	NEXAFS, XPS	Catalysis, Energy, Quantum
6	Soft & Tender Imaging	180 eV - 8 keV	TXM, FIB-TXM Tender TXM, Tomography	Life Sciences, Energy Life Sciences, Energy
	DIP	20 eV 1.5 keV	Soft X-ray spectroscopy	Catalysis, Energy, Quantum
7	Inelastic Scattering	180 eV - 3 keV	RIXS meV@1keV RIXS	Quantum, Energy Catalysis Quantum, Energy, Catalysis
	DIP	20 eV - 1.5 keV	Soft X-ray Dynamics	open port
8	Spectro Microscopy	100 eV - 1.8 keV	(S)PEEM, PEEM, Ptychography nano-ARPES	Quantum, Energy, Catalysis Quantum, Energy, Catalysis
	DIP	100 eV - 4 keV	Broad band soft + tender X-ray spectroscopy	open port
9	Macromol. Crystallography	5 - 20 keV	X-ray Diffraction X-ray Diffraction	Life Sciences Life Sciences
	DIP	80 eV - 2 keV	Soft X-ray spectroscopy	open port
10	Multimodal Spectroscopy	20 eV- 8 keV	Multimodal Spectroscopy Time-resolved spectroscopy	open port open port
	DIP	20 eV - 3 keV	Declined beamline, Multimodal spectroscopy	Catalysis
11	PTB: PGM/EUV	60 eV - 1.85 keV	Reflectometry / Scatterometry Reflectometry / Scatterometry	Metrology for Industry Metrology for Industry
	DIP PTB: FCM	1.7 keV - 11 keV	X-ray radiometry / X-ray reflectometry	Metrology
12	PTB: PGM/RFA	80 eV - 2 keV	X-ray spectrometry X-ray spectrometry	Materials Metrology Materials Metrology
	DIP PTB: white light	40 eV - 20 keV	Primary source standard BESSY III	Metrology
13	PTB: Tender X-ray	1 keV - 10 keV	µ-XRF/ (GI)SAXS / Ptychography µ-XRF/ (GI)SAXS / Ptychography	Materials Metrology, Energy Materials Metrology, Energy
	DIP PTB: XPBF/ESA	1 keV - 3 keV	X-ray optics for astrophysics	in-line Metrology for Manufacturing
14	BAMline	5 keV - 120 keV	Diffraction, XRF, µCT Diffraction, XRF, µCT	Materials Metrology Materials Metrology

1st Milestone Lattice: HOA - Linear Beam Dynamics

LEGO approach - UC - Angle distribution between UC & DSC

Distribution of bending angles

$$\epsilon_0 \sim \phi^3$$

- 16 sectors → 360/16 = 22.5°
- With a 6-MBA: ½ + 4 + ½
  - 2.25° + 4.5° + 4.5° + 4.5° + 4.5° + 2.25°
- For our 6-MBA with 16 straights it is a 20-30% reduction
  - at UC ~ 4.0° and DSC ~ 3.25°