Status of the BESSY III Lattice

Moving towards the TDR Phase

P. Goslawski for the accelerator team

10th Low Emittance Rings Workshop 2025, DESY, Hamburg, Germany

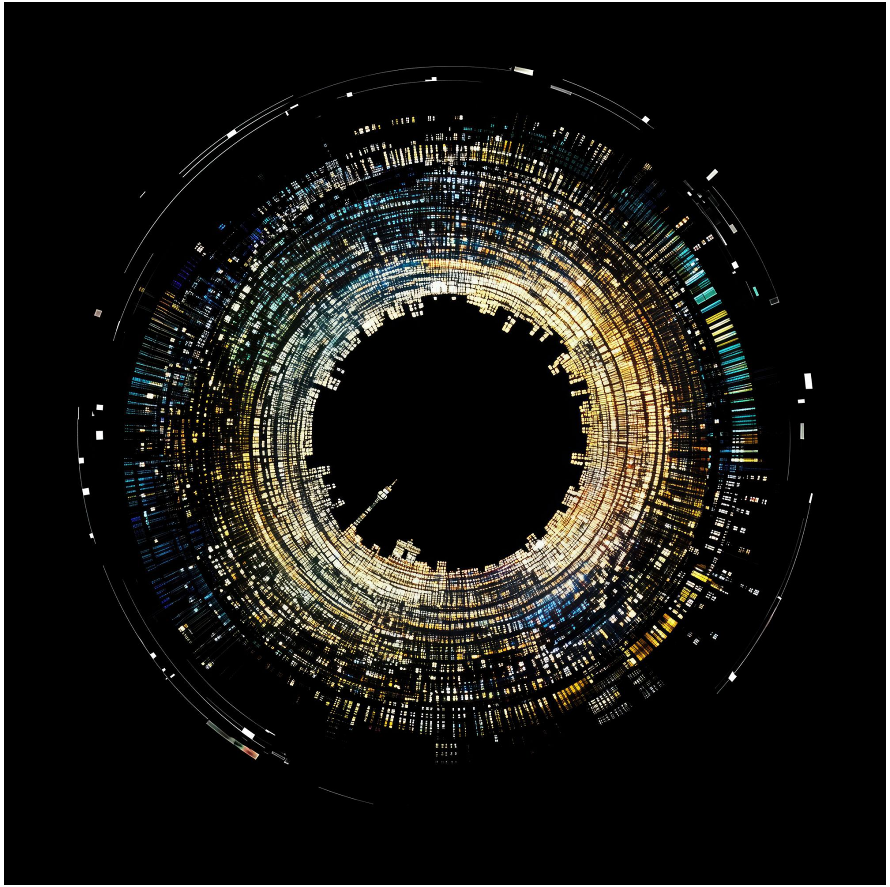
Moving towards/in the CDR/TDR phase

Overview

- Goal → Design parameters
- What do we have ? → CDR, a 1st self-consistent lattice
  - One bare lattice (two, three, four, …, conceptional)
- What is next / What is going on ?
  - One real technical lattice - A simulated commissioning lattice

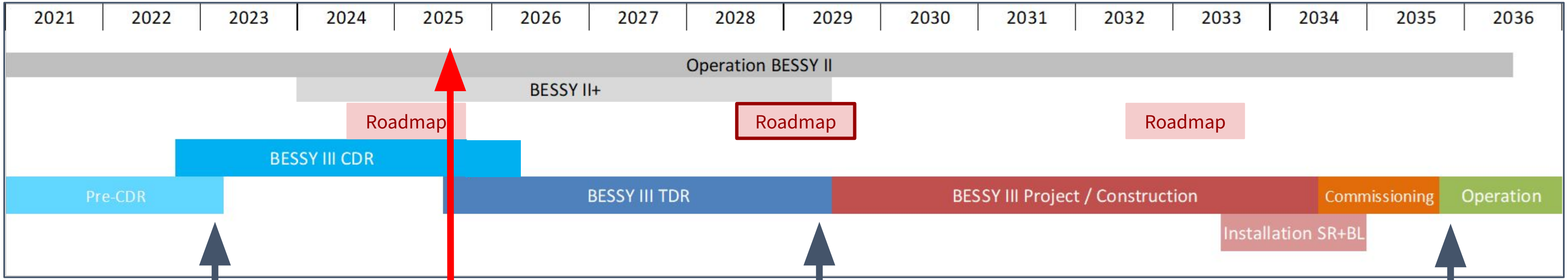
    → injection, orbit/optics correction, TDR
- Outlook

BESSY III



Time schedule

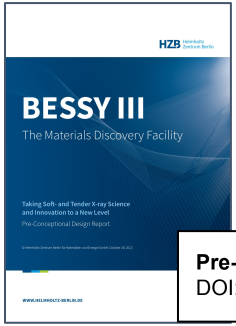
Courtesy: **Markus Sauerborn**



submission & positive review of pre-CDR

earliest start of construction work on Adlershof site

earliest start of full user-operation



Pre-CDR
DOI: 10.5442/r0004

Greenfield: “No” limitations of an existing facility

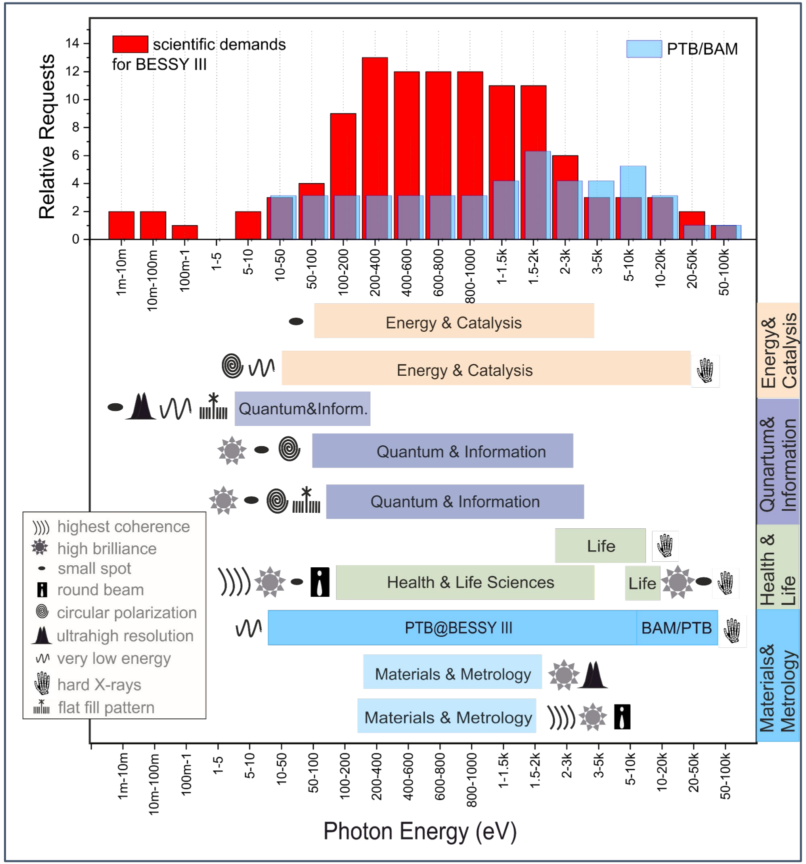
2035: Long project duration

BESSY II/MLS: As testbed for hardware & software

Some Freedom for more lattice design, for more simulated commissioning, for a better digital workflow of describing a storage ring (lattice),
For a coherent science case, for solid and/or unique experiments !

What do we have?

Courtesy: **K.Holldack, Z.Hüsges**



BESSY III Requirements & Objectives

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

Ring parameters

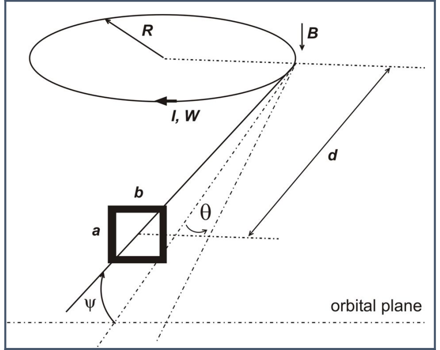
1. Ring Energy **2.5 GeV** (1.7 GeV)
2. Emittance **100 pm rad** (5 nm rad)
3. Circumference **350 m** **16 straights @ 5.6 m** (240 m @ 4 m)
4. Low beta straights & round beams
5. **Metrology source Homogenous bends** Measuring he field at the source point with a NMR probe in a volume of 10x10x10 mm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

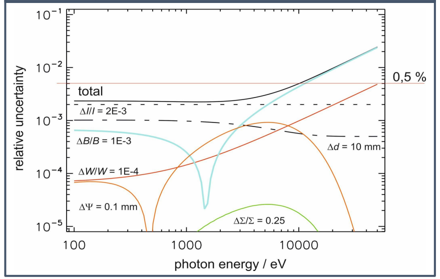
Already at BESSY II, a 3rd generation **without** combined function bends

What do we have?

Stability

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



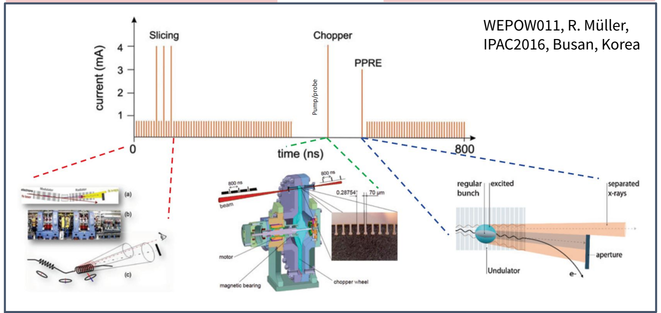


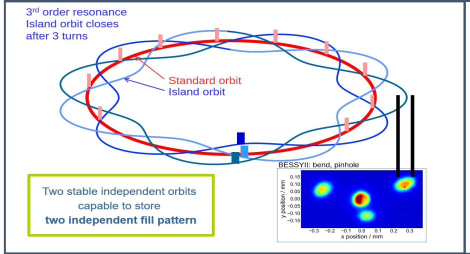
Courtesy: Michael Kumrey, PTB

Objectives for Lattice Design

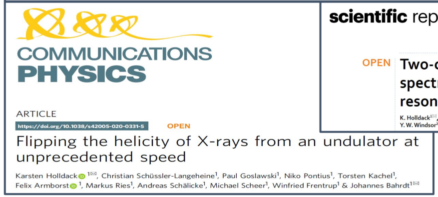
Flexibility

Timing modes
Short pulses
Repetition rate





Low α &
sc or **nc VSR**

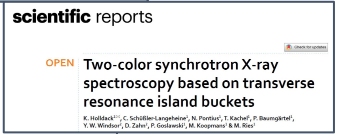

COMMUNICATIONS PHYSICS

ARTICLE

https://doi.org/10.1038/s42005-020-0331-5 OPEN

Flipping the helicity of X-rays from an undulator at unprecedented speed

Karsten Holldack, Christian Schüssler-Langeheine, Paul Goslawski, Niko Pontius, Torsten Kachel, Felix Armborst, Markus Ries, Andreas Schälicke, Michael Scheer, Winfried Frentrup & Johannes Bahrdt

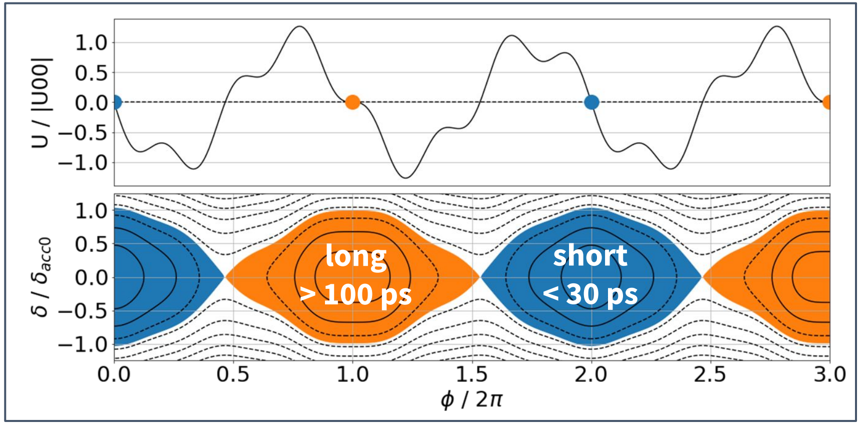

scientific reports

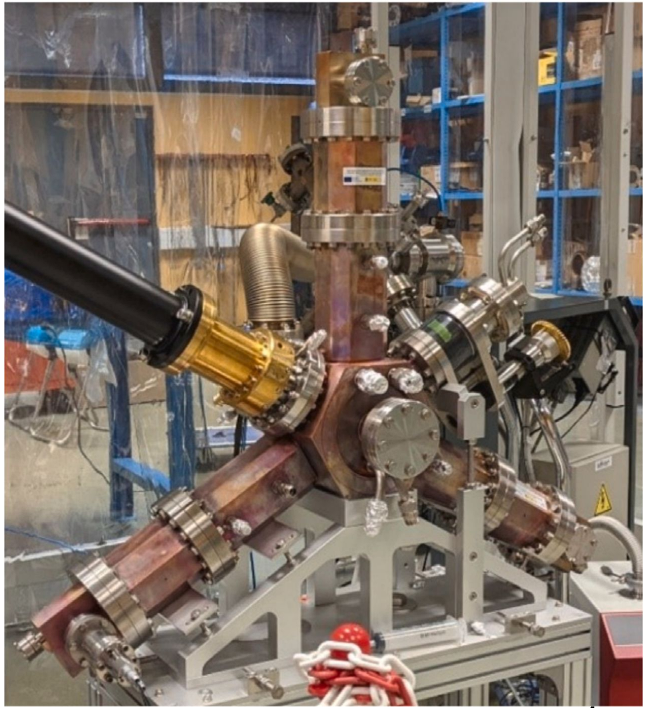
OPEN Two-color synchrotron X-ray spectroscopy based on transverse resonance island buckets

Higher-Harmonic cavity[1] + Variable Pulse Length Storage Ring

- 3rd and 3.5th harmonic (1.5 GHz & 1.75 GHz) cavities
  - Increase lifetime and relax IBS
  - Allow longitudinal beating scheme (short + long bunches)

→ Preservation of 10 ps bunch length





Active harmonic EU cavity[1]

[1]F. Perez, 10.1016/j.nima.2024.170195

What do we have?

Objectives for Lattice Design

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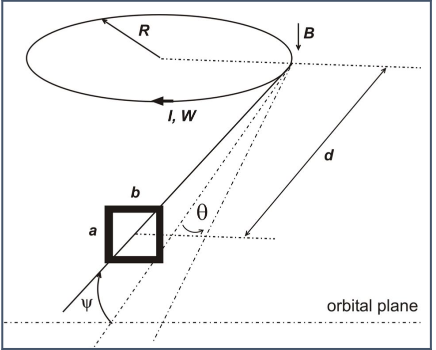
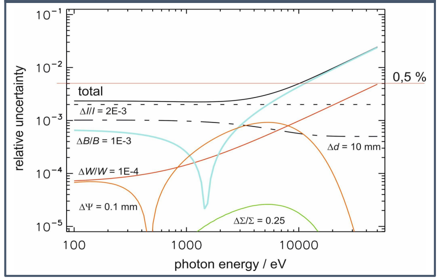
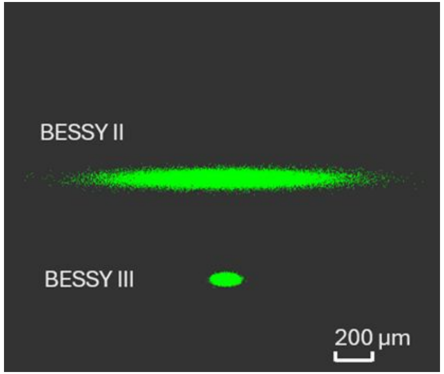




Courtesy: Michael Kumrey, PTB

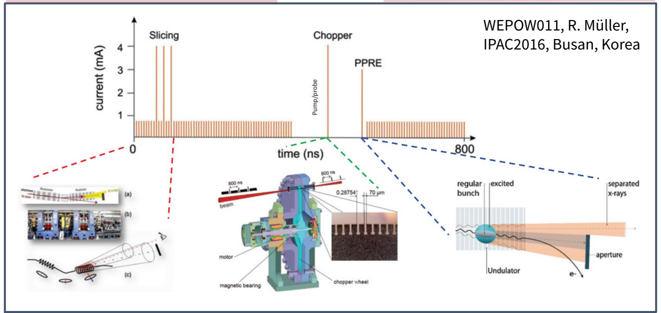
We want more then emittance.
Emittance with
Stability & Robustness & Flexibility!

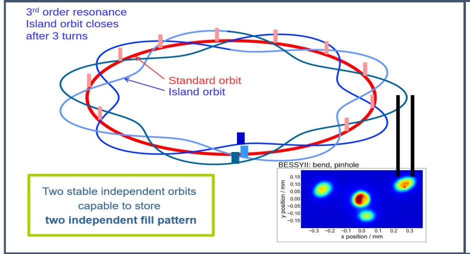
Emittance with relaxed nonlinear beam dynamics & at least one metrology bend



Flexibility

Timing modes
Short pulses
Repetition rate





Low α &
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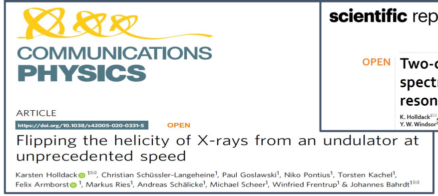
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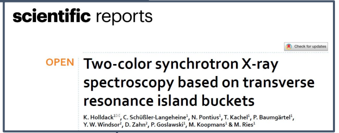
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OPEN Two-color synchrotron X-ray spectroscopy based on transverse resonance island buckets

K. Holldack, C. Schüßler-Langeheine, N. Pontius, T. Kachel, P. Baumgärtel, Y. W. Windsor, D. Zahn, P. Goslawski, M. Koopmans & M. Ries

What do we have? - A starting point: the HO-MBA

The Higher Order Achromat, HO-MBA

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

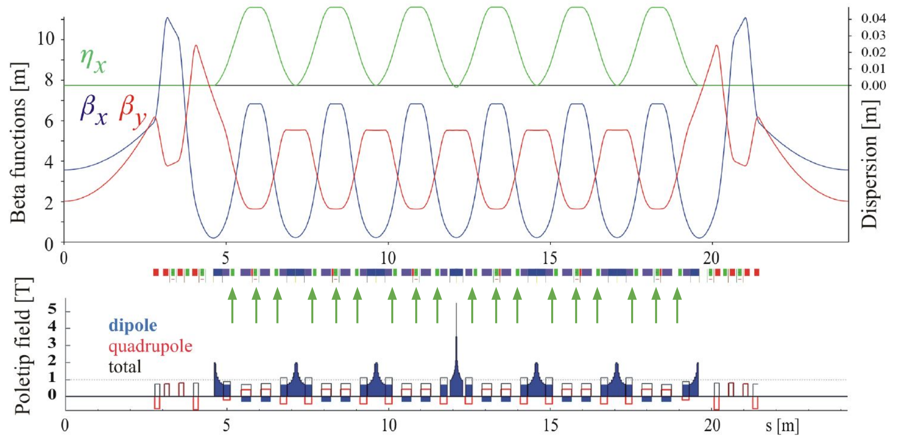


Figure 2.3: Optical functions and field components for one 7BA-arc where the center LGB has been interchanged by a super-LGB of 5.5 T peak field. Bending magnets are in dark blue, quadrupoles red and se… …les green.

Sext. distributed
LGB - yes
RB - yes

The Hybrid, HMBA

- ESRF-EBS, PETRA IV … above 3 GeV
  - P. Raimondi

PANTALEO RAIMONDI and SIMONE MARIA LIUZZO PHYS. REV. ACCEL. BEAMS **26,** 021601 (2023)

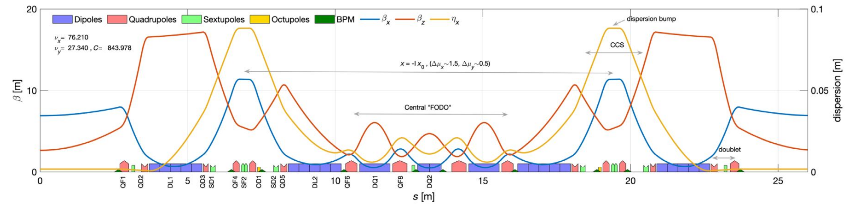


FIG. 4. Optics functions and magnet layout for the EBS H7BA cell.

TOWARD A DIFFRACTION LIMITED LIGHT SOURCE PHYS. REV. ACCEL. BEAMS **26,** 021601 (2023)

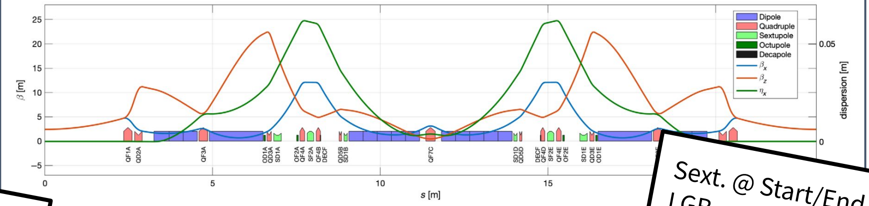


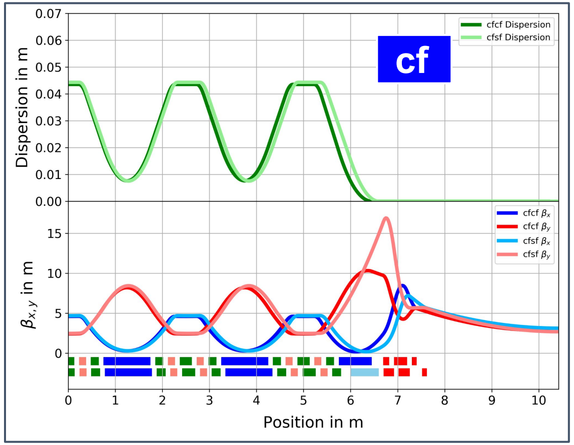
FIG. 5. Optics functions and magnet layout for an H6BA lattice cell designed for a 6 …

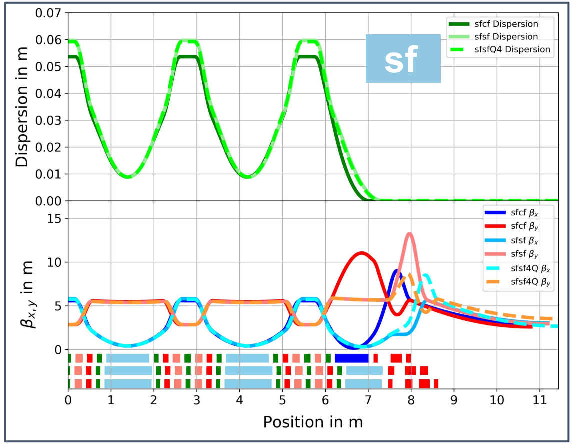
Sext. @ Start/End
LGB - yes
RB - no

$$\epsilon_{x,e^-} \sim E^2/N_d^3 \qquad x_D = D \cdot \Delta p/p$$

What do we have?

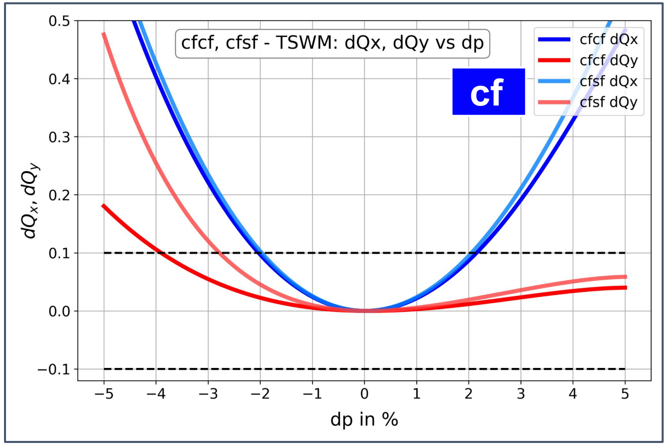
More than one BESSY III lattice candidate

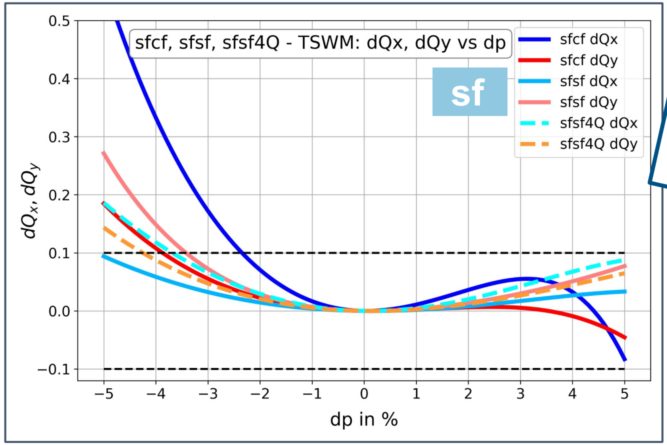




TSWM
Chromatic Tune Shift

With two sextupole families only: Sx, Sy





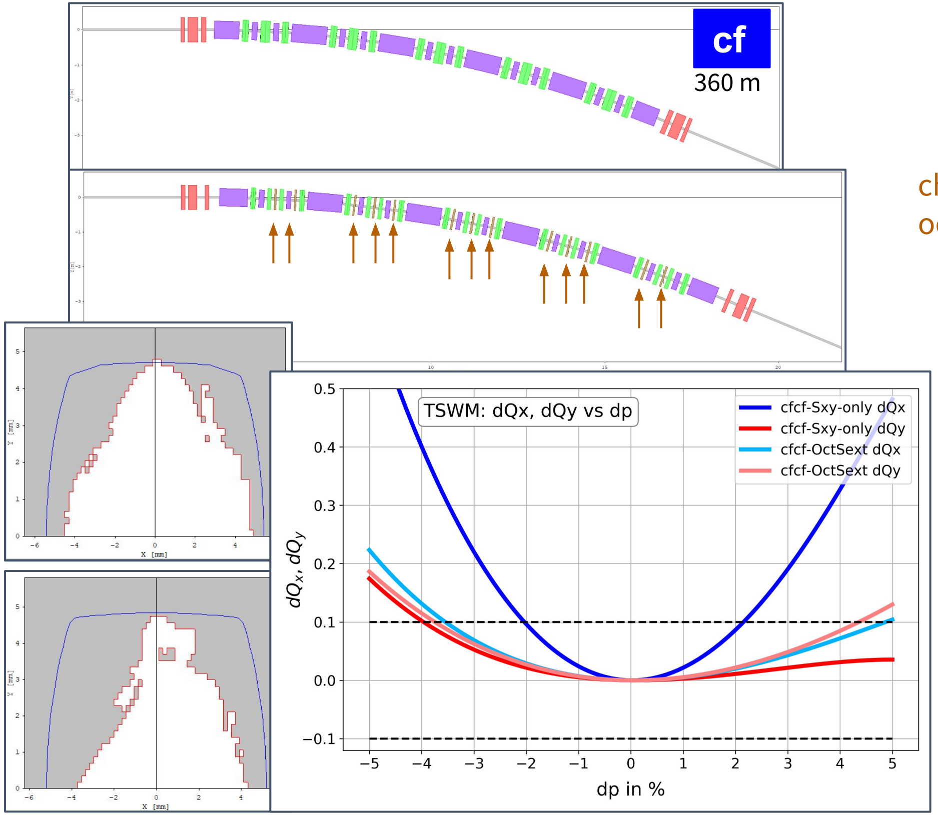
The flatter the curve the better
→ Robustness, Lifetime

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

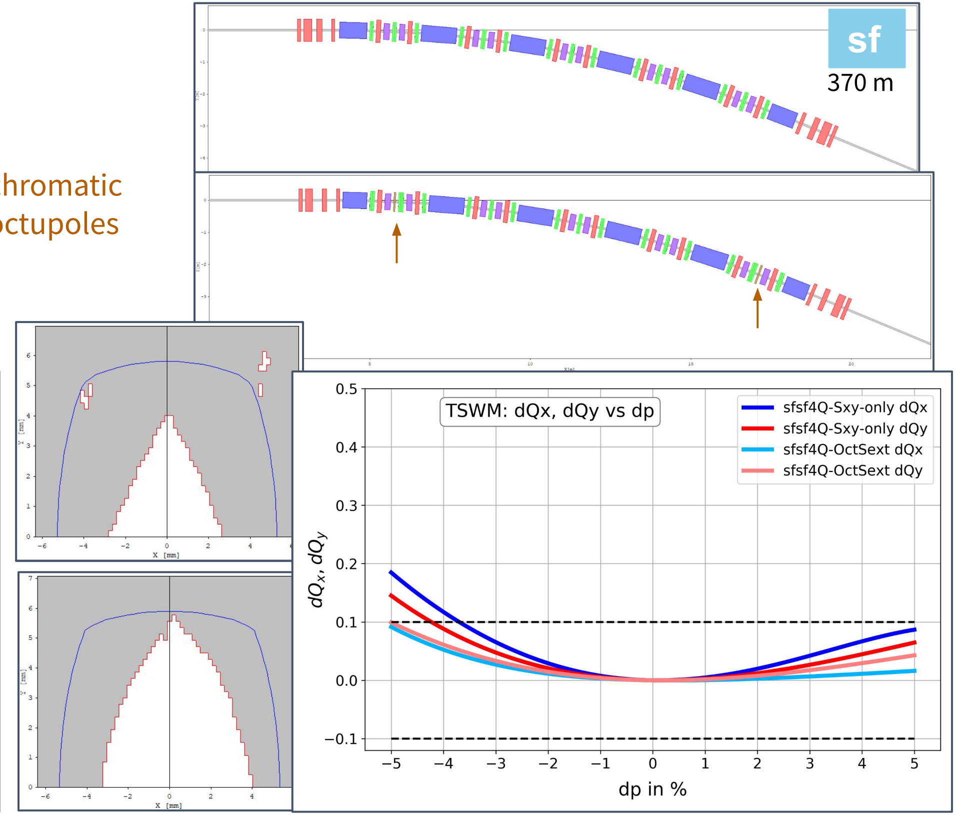
Non-Linear Beam Dynamics - Sextupole Split Up

In progress

Non-linear optimization



chromatic octupoles

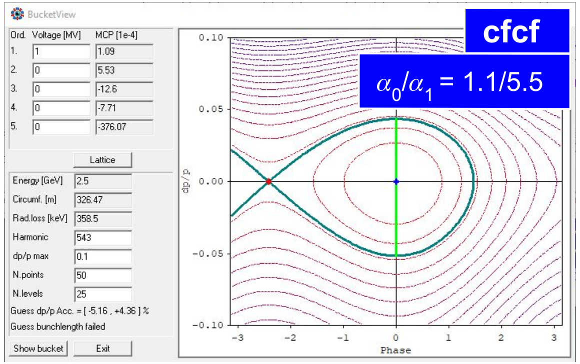


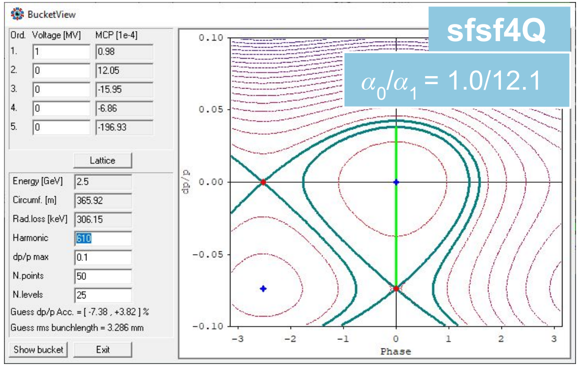
Alpha buckets - higher order of mom.com

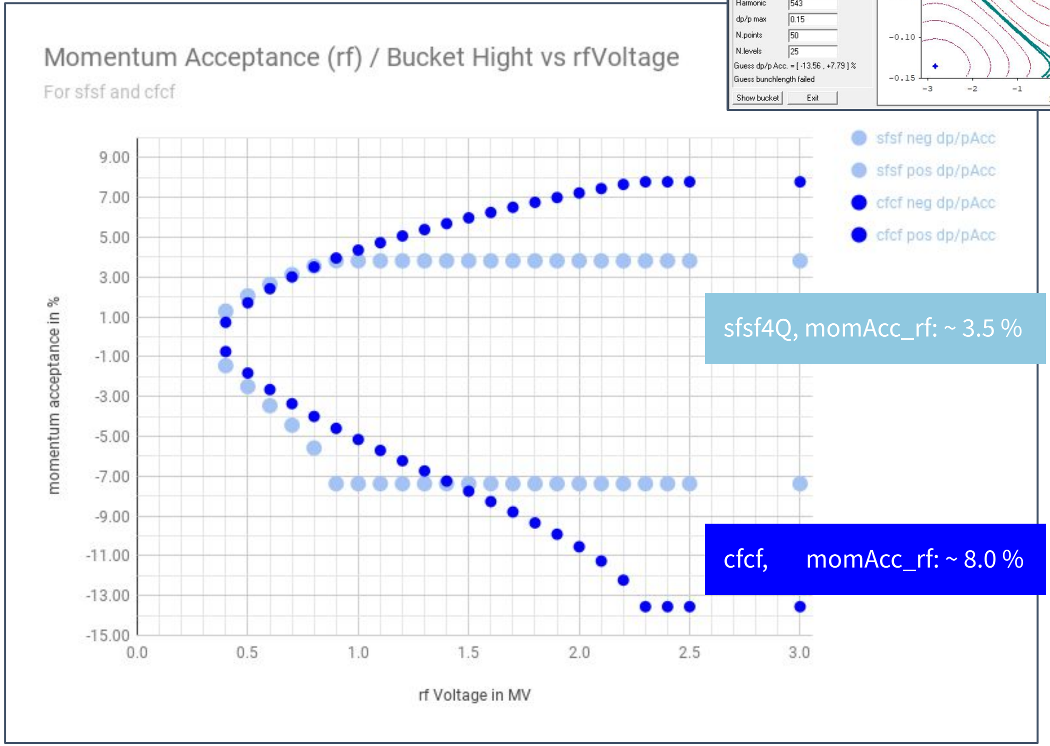
Thanks to A.Streun

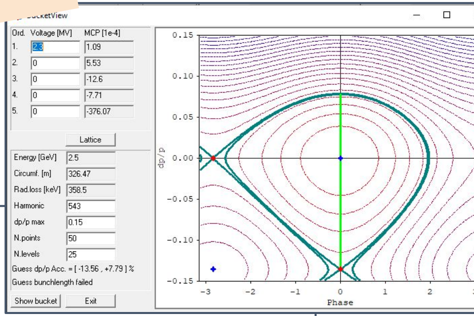
Limiting the momentum acceptance in the longitudinal plane

- cfcf, sfsf4Q





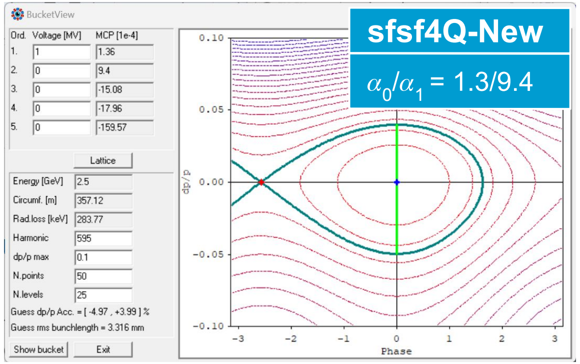


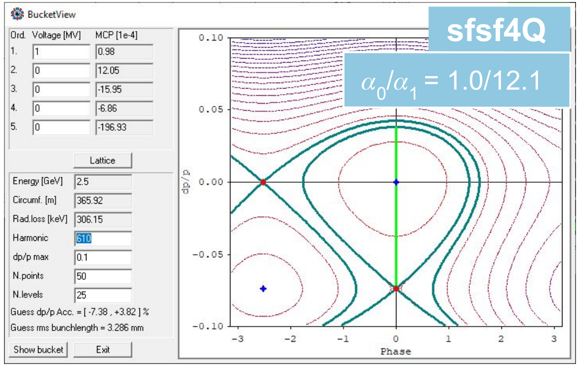


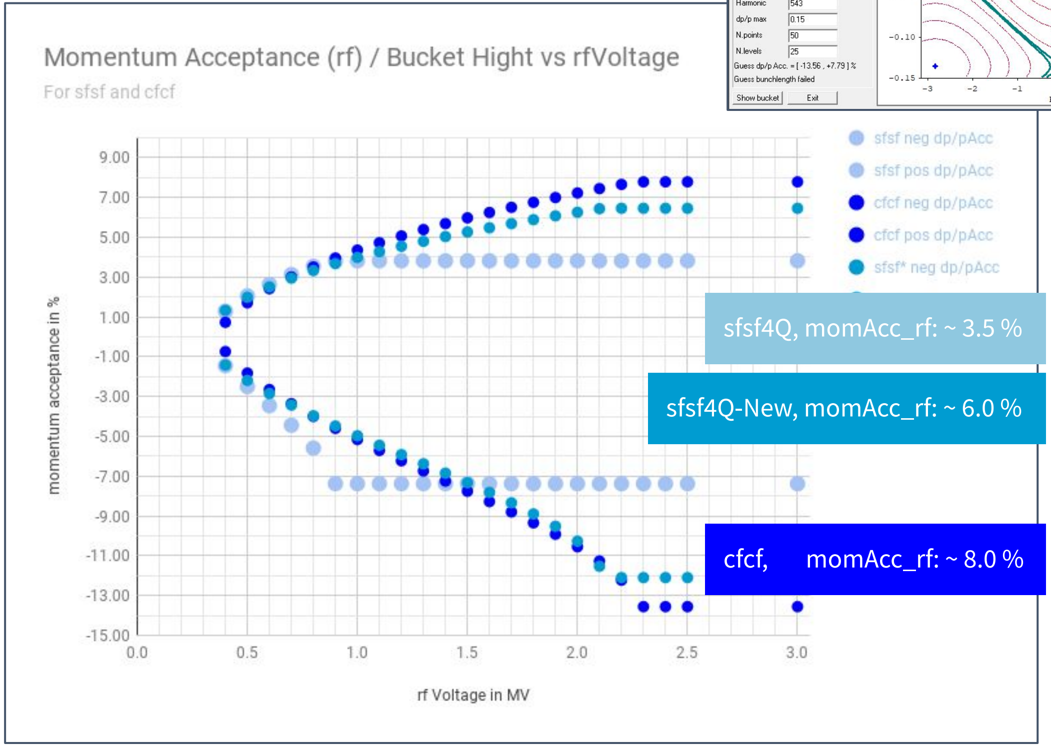
Alpha buckets - higher order of mom.com

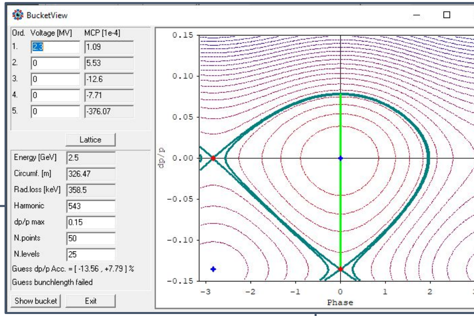
Limiting the momentum acceptance in the longitudinal plane

- cfcf, sfsf4Q, sfsf4Q-New









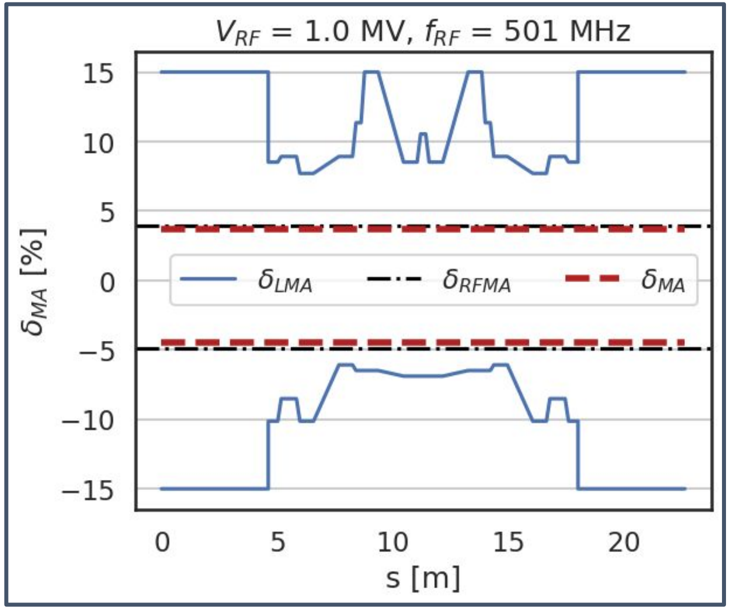
Local momentum acceptance

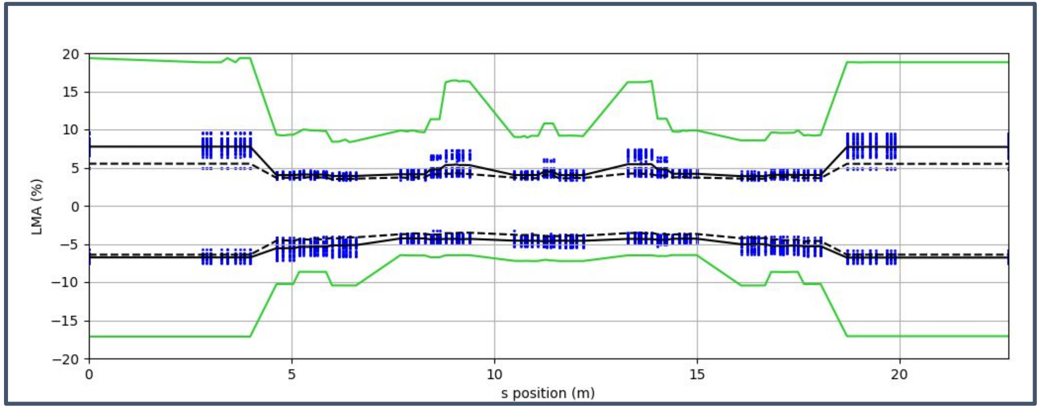
Chromatic tune shift and rf momentum acceptance well adapted/matched

Well balanced non-linear setup, by matching:

- Transverse chromatic tune shift -
  momentum acceptance of the transverse dynamics

- The rf momentum acceptance, given by the long. dynamics

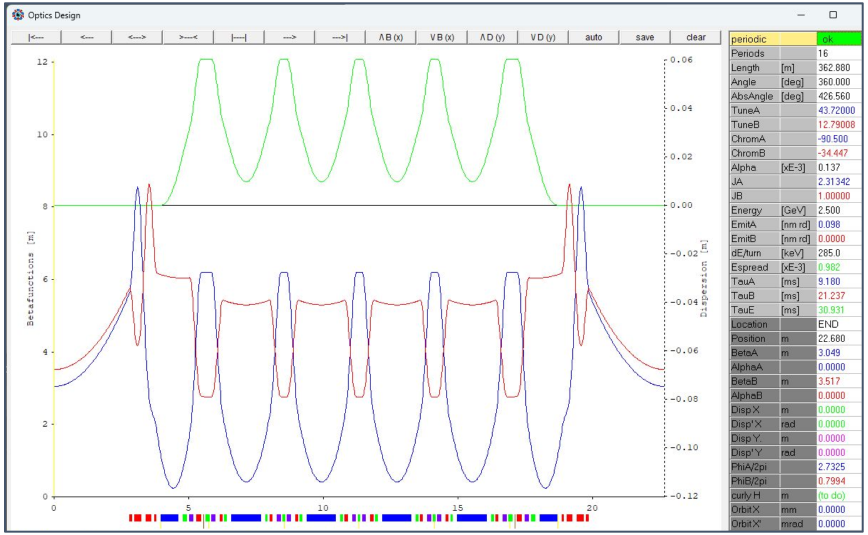




What do we have?

Bare Lattice(s) (HOA, hybrid not studied yet)

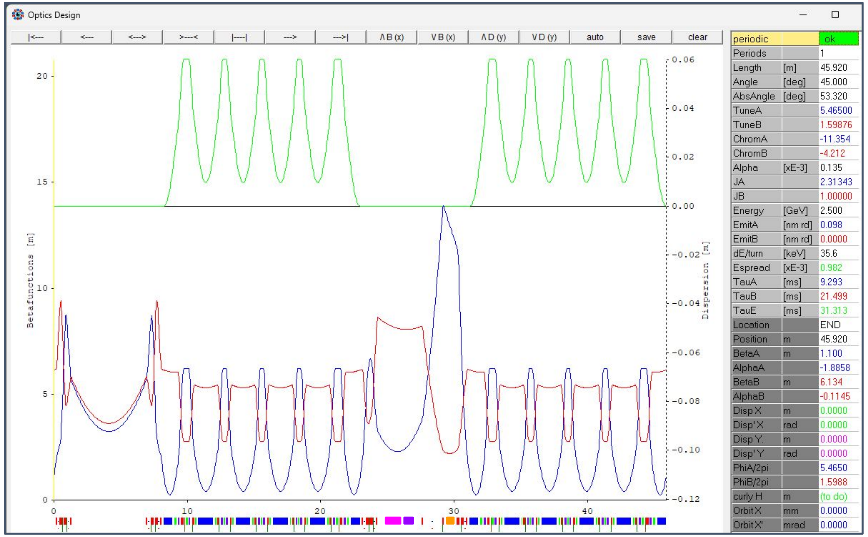
- Pure fundamental lattice - periodic sector cell:
  Only big beam guiding elements: bends, quads, sexts
- Only two sextupole families (SF, SD) to correct natural chromaticity → start of non-linear dynamics
- First non-linear optimisation - sextupole split up, octupoles



Simulated Commissioning Lattice

Real Technical Lattice

- Perturbing the periodic sector cell:
  Injection straight & straight ID adaption
- First non-linear optimisation - sextupole split up, octupoles
- Robustness analysis: Misalignments, SC
  Correction Schemes: Orbit Correction (BPMs & Corr.), ..



Real Lattice

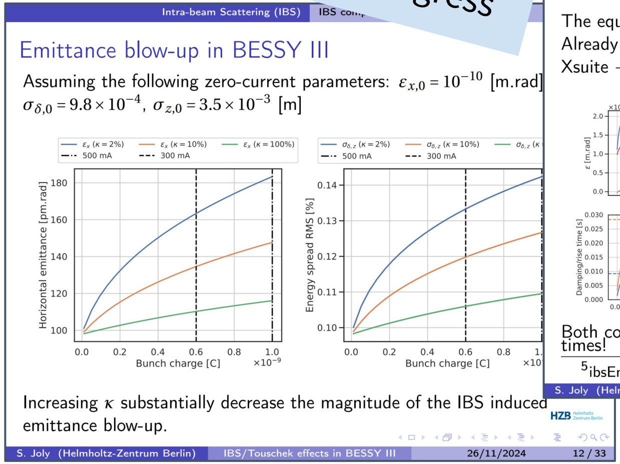
What is next/going on?

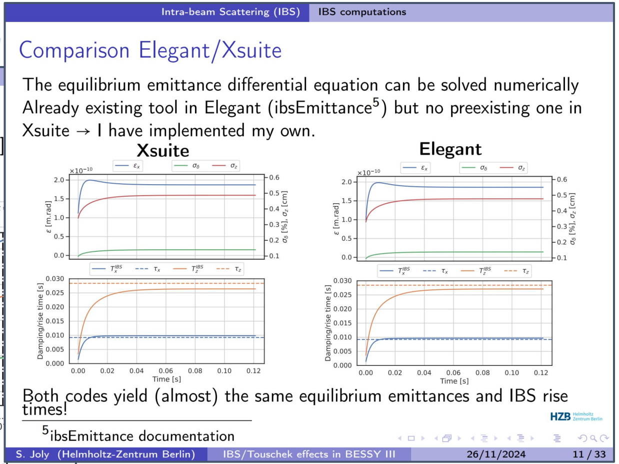
Courtesy: **S.Joly**

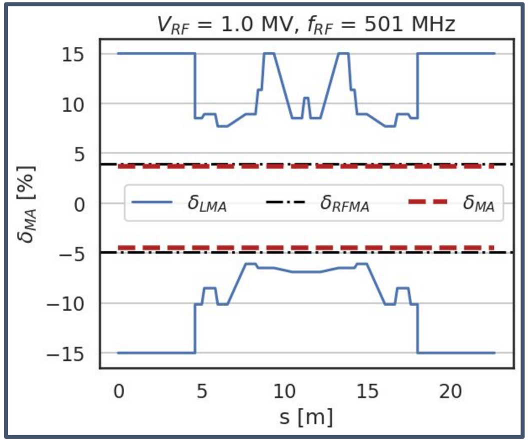
Real Technical Lattice, SC Collective Effects

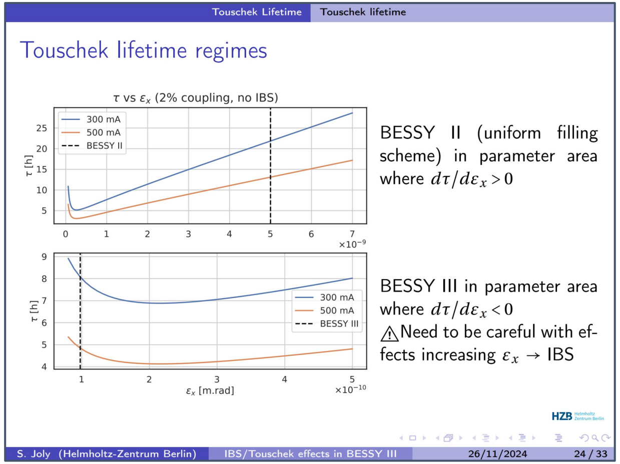
In progress

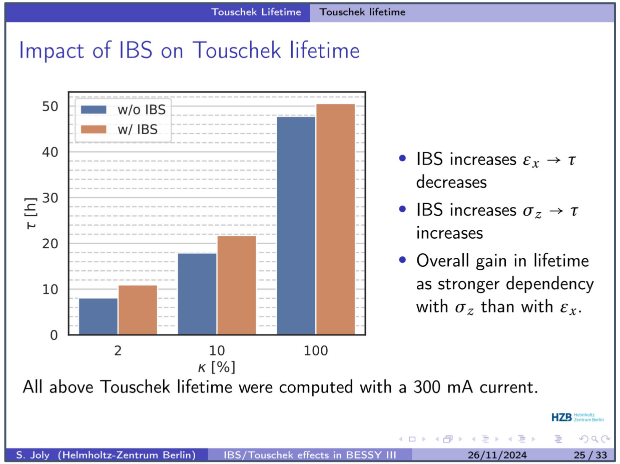
- **IBS** estimate…
  with Xsuite & elegant
- **Touschek Lifetime…**
  with pyAT, pySC, …











What is next/going on?

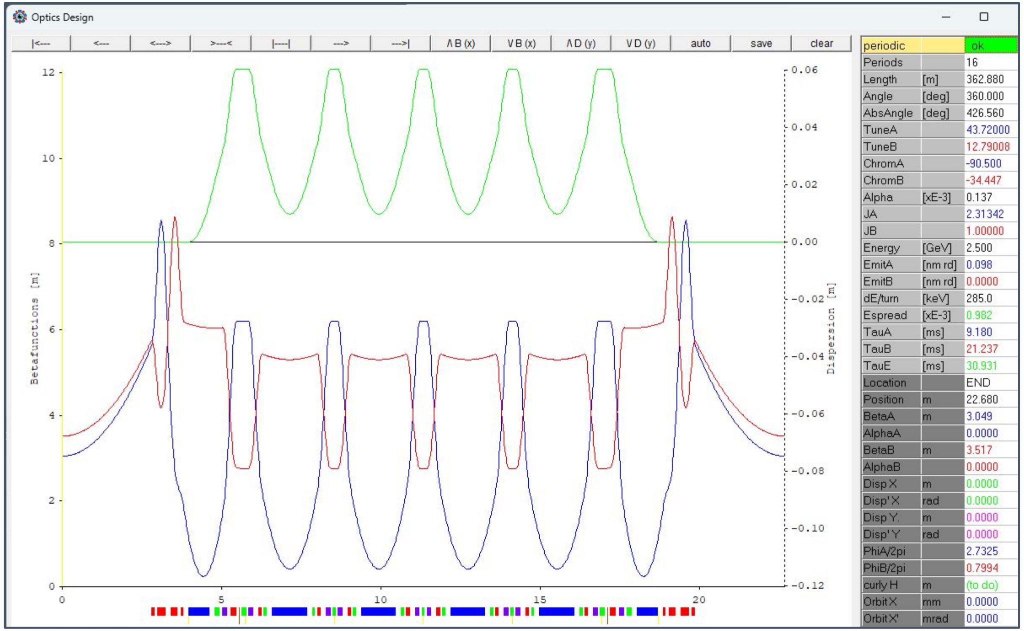
Courtesy: **M.Abo-Bakr, P.Goslawski**

In progress

Real Technical Lattice, SC Injection

- How to inject into a/our 4th gen. MBA lattice?
  - 4-Kicker Injection, Single Kicker Injection
  - **Non-Linear Kicker (NLK) Injection**
  - Swap-In Swap-Out Injection

- For (horizontal) injection one needs large (horizontal) amplitude acceptance, given by the large beta_x-function
  - For 4-kicker injection it needs to be high at the septum (phase advance unimportant)
  - For NLK injection, it needs to be high at the non-linear kicker (phase advance important)



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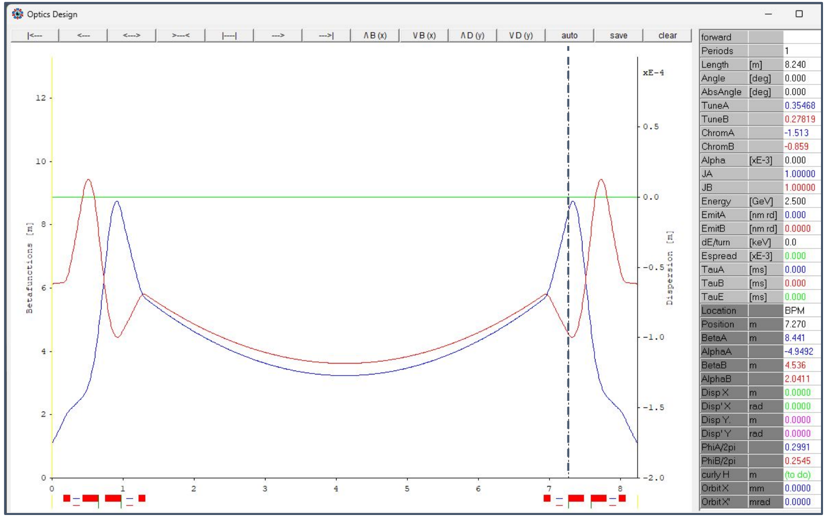
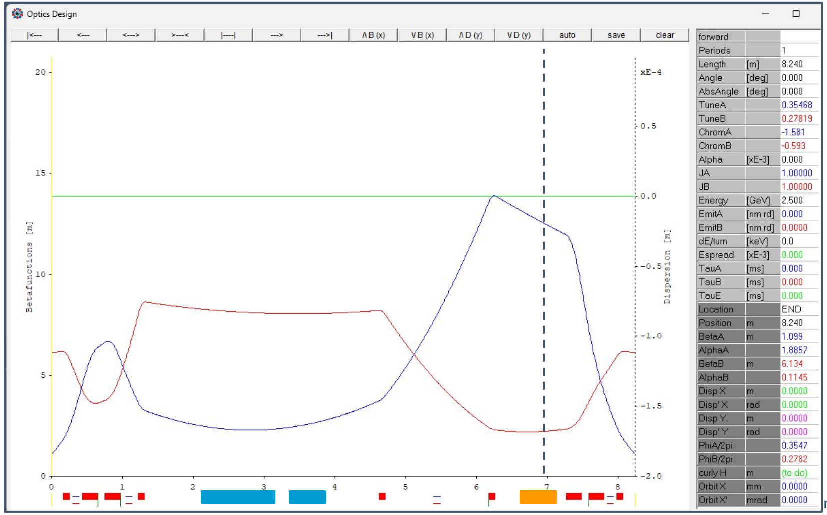


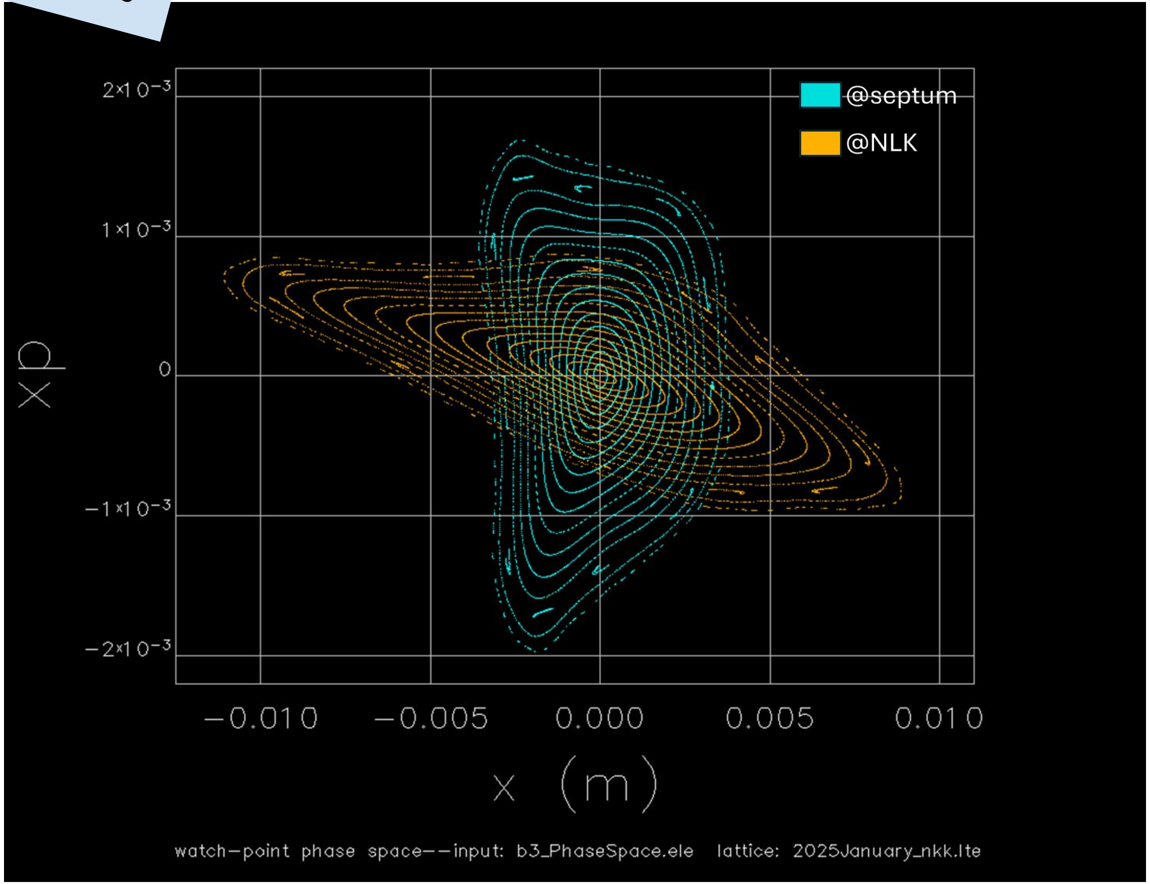


What is next/going on?
Courtesy: **M.Abo-Bakr, P.Goslawski**

In progress

Real Technical Lattice, SC Injection

- Horizontal phase space and injected bunch at
  - Septum
    - a
    - b
  - non-linear kicker
    - c
    - d



HZB BESSY II Light Source

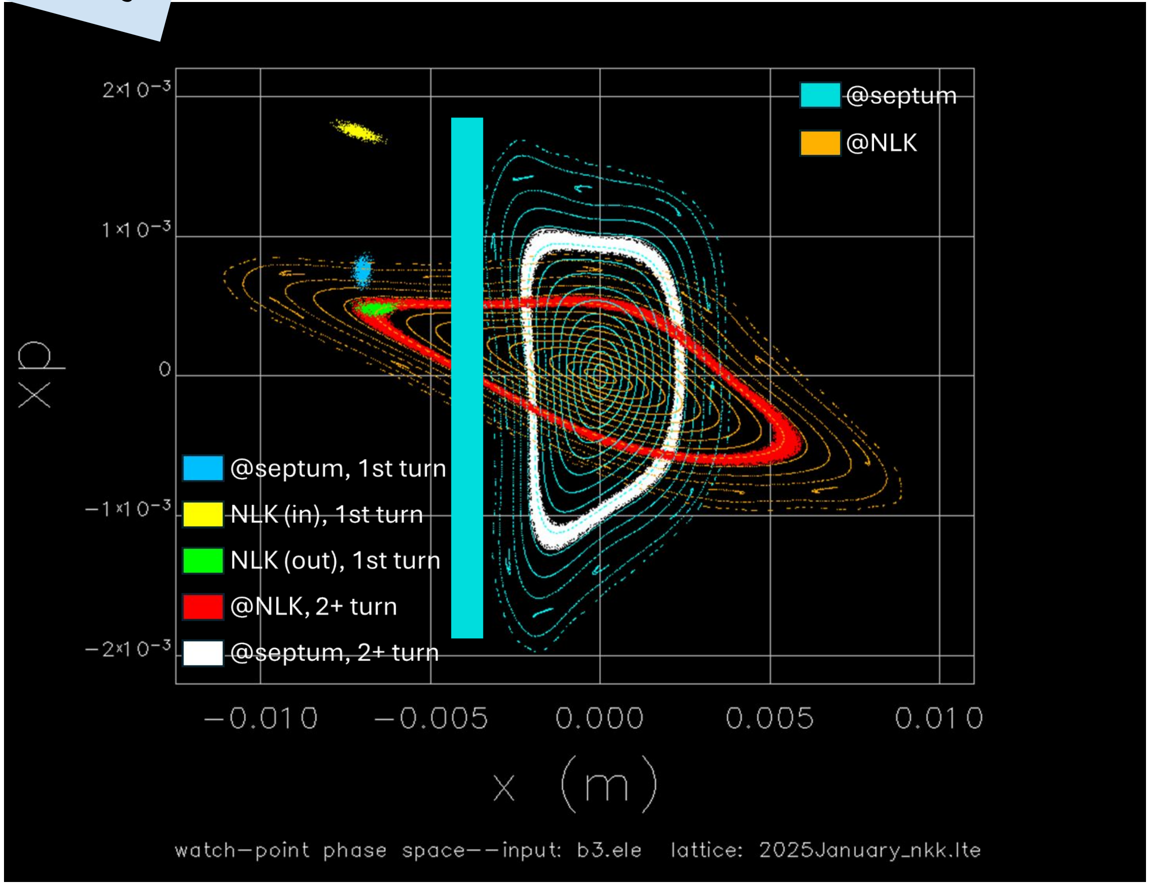
What is next/going on?

Courtesy: **M.Abo-Bakr, P.Goslawski**

Real Technical Lattice, SC Injection

In progress

- Horizontal phase space and injected bunch at
  - Septum
    - From the injector
  - non-linear kicker
    - Before the kick
    - After the kick
  - As stored beam
    - at the septum
    - At the non-lin. kicker



What is next/going on?

Courtesy: **S.Joly, B.Alberdi, M.Arlandoo**

In progress

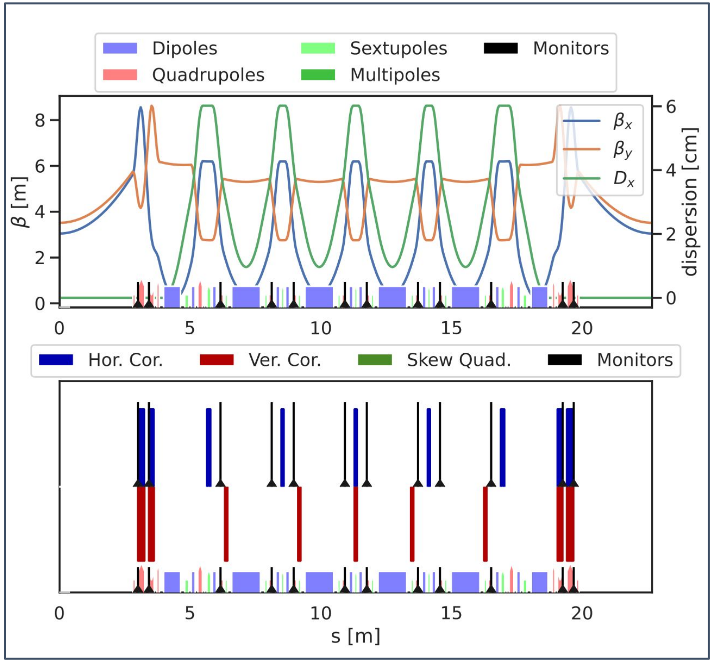
Real Technical Lattice, SC

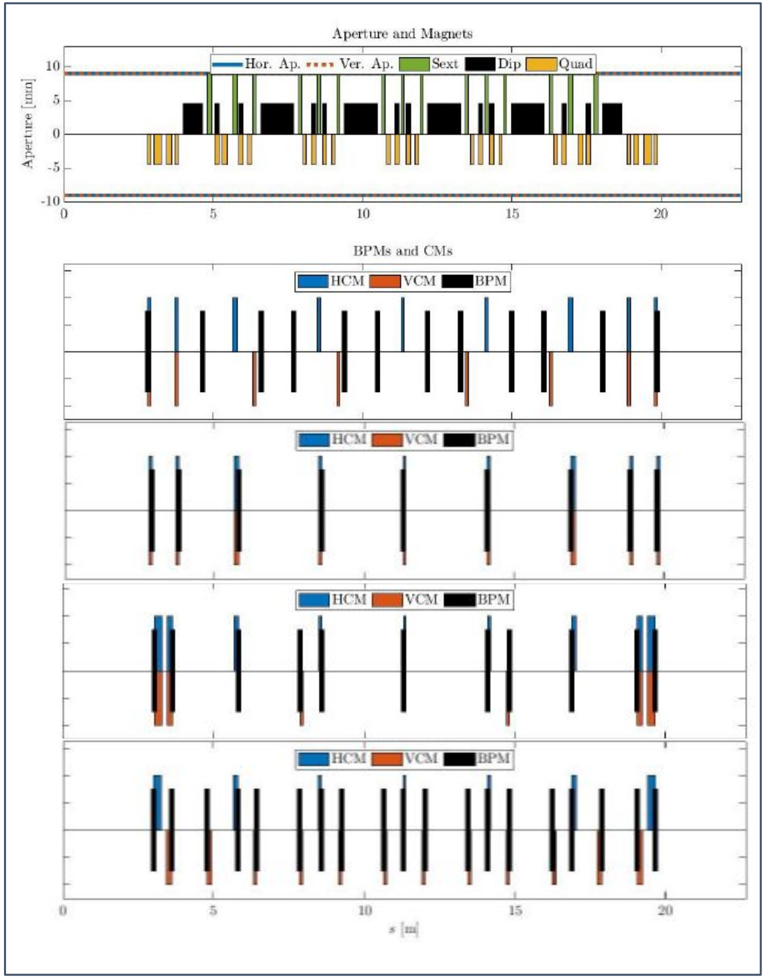
Orbit Correction, Optics Correction

- **Orbit correction, BPM & corrector scheme** with pyAT-SC, matlab-AT-SC

AT Collaboration
Accelerator Toolbox

(elegant, opa)



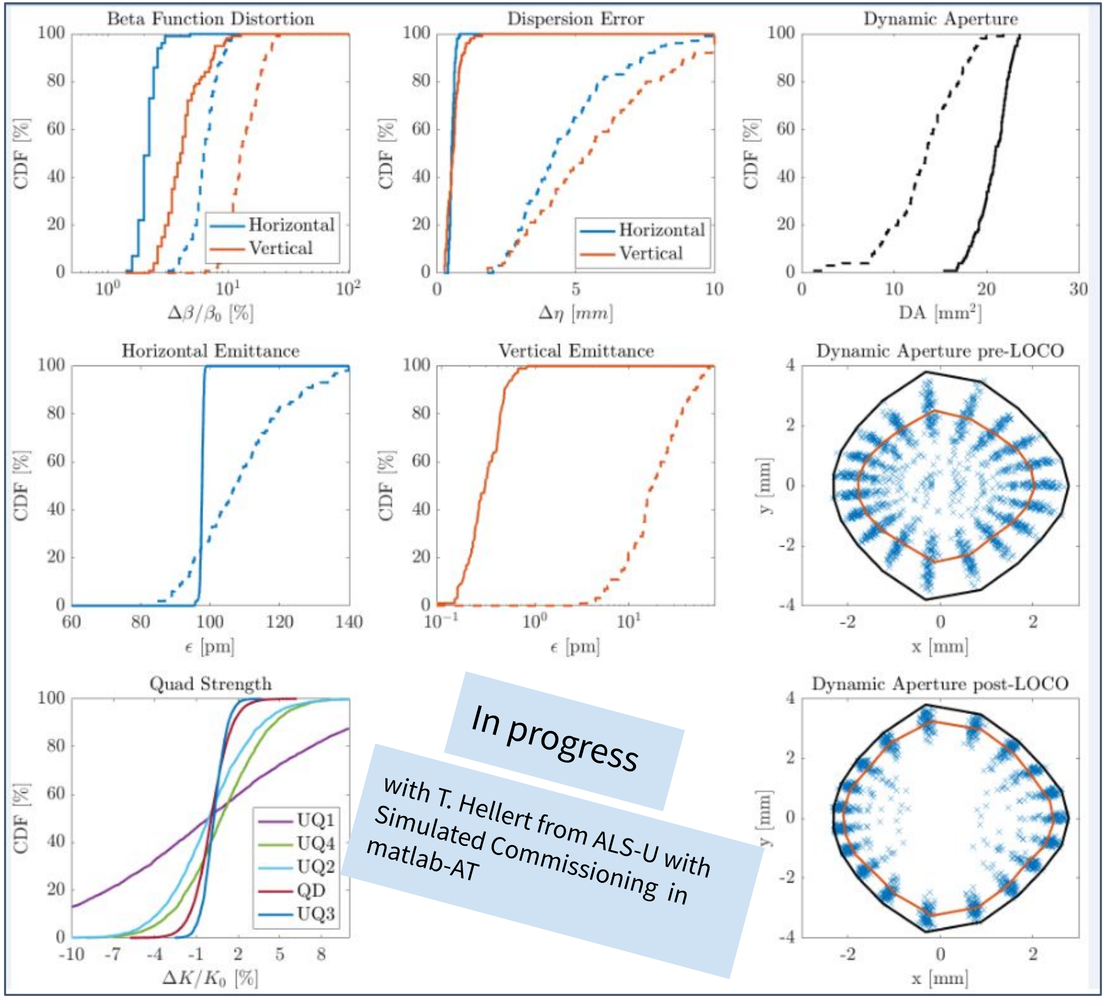


What is next/going on?

Courtesy: **T.Hellert, B.Alberdi**

Real Technical Lattice, SC Robustness Analysis, Tolerances

- SC with matlab-AT-SC (T.Hellert, B.Alberdi)
- SC with pyAT-SC (L. Malina, S. Joly)



In progress

with T. Hellert from ALS-U with Simulated Commissioning in matlab-AT

What is next/going on?

Courtesy: **T.Hellert, B.Alberdi**

Real Technical Lattice, SC Robustness Analysis, Tolerances

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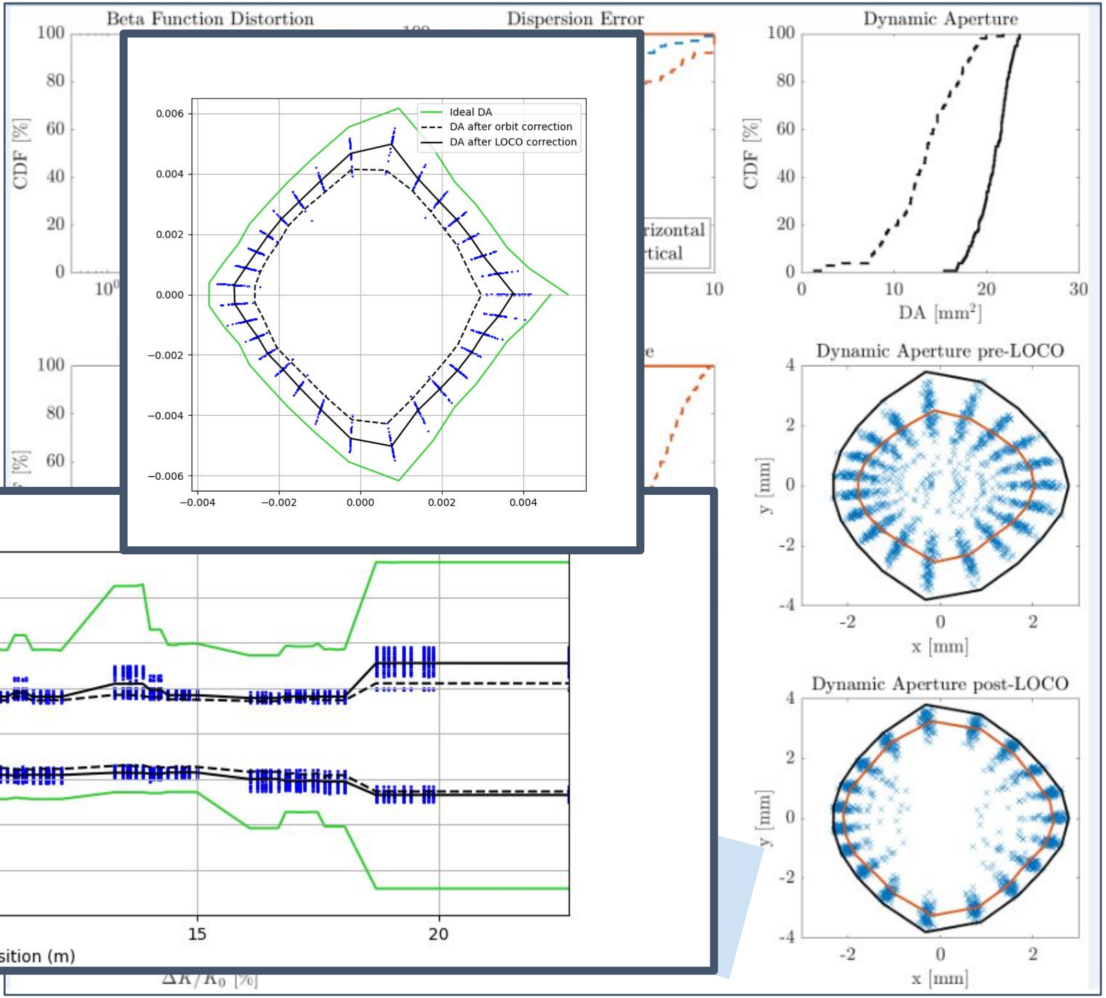
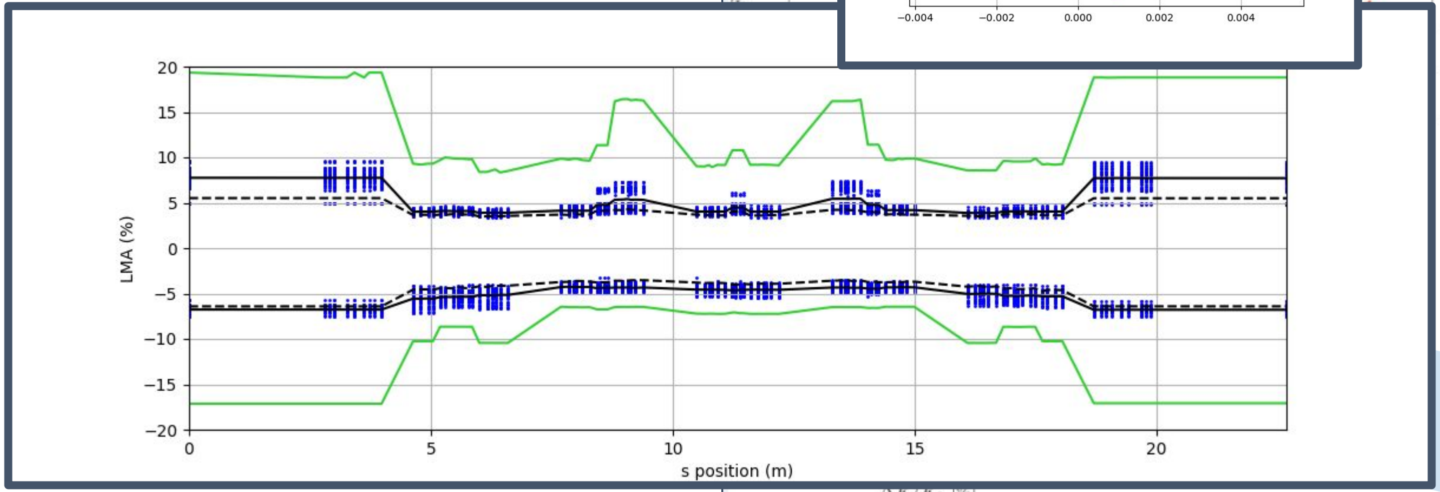
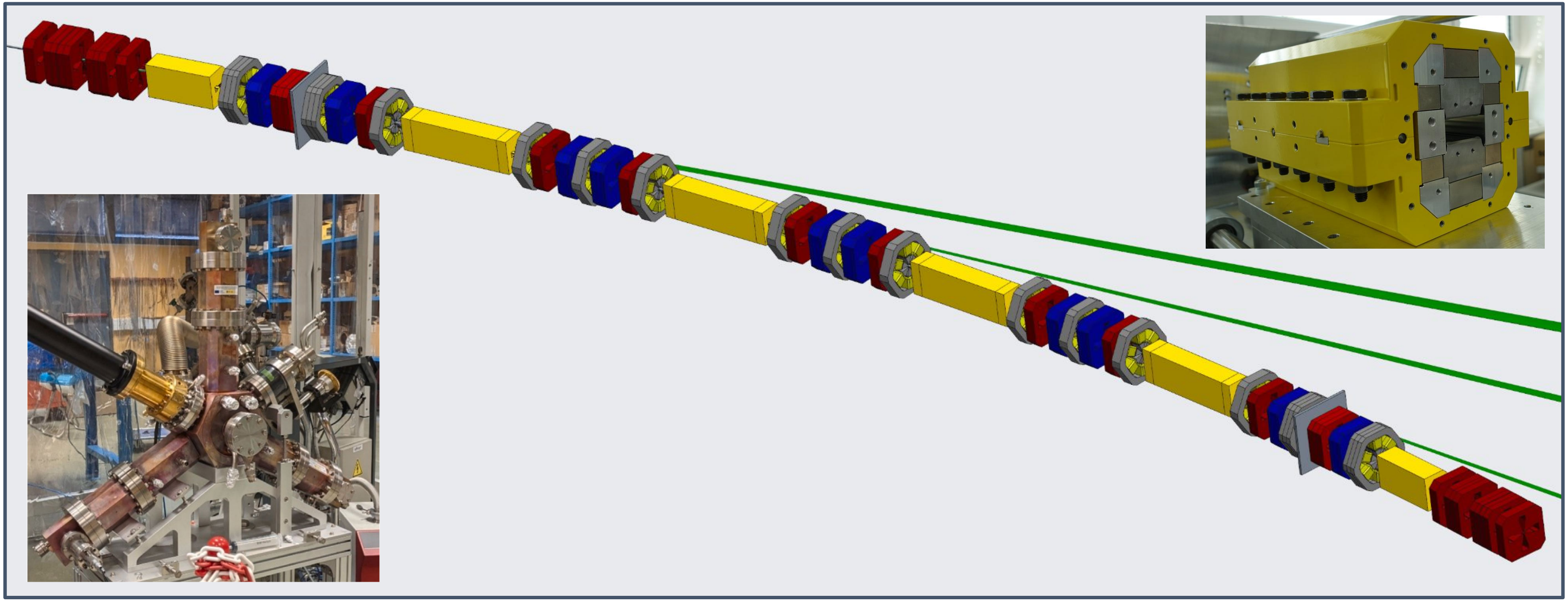




Questions ?

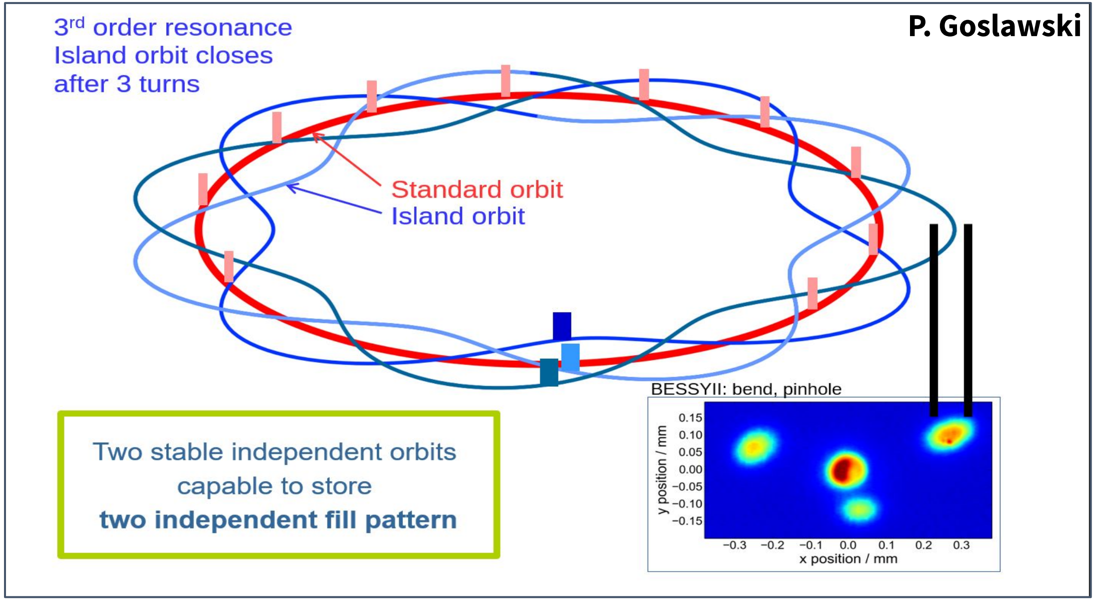


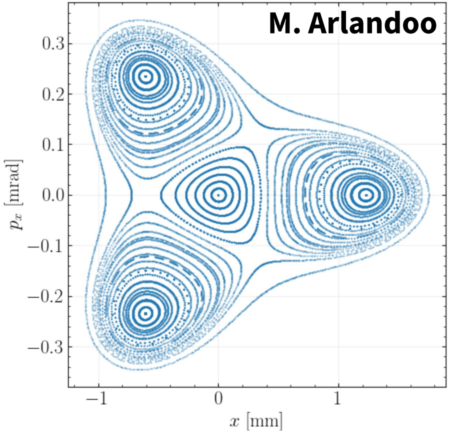
Thanks for your attention!

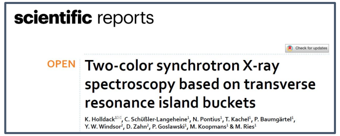
Backup Slides

Transverse Resonance Island Buckets user mode

- Experience with Transverse Resonance Island Buckets (TRIBs) which was successfully demonstrated in BESSY II
- **Can be achieved in BESSYIII[1]**





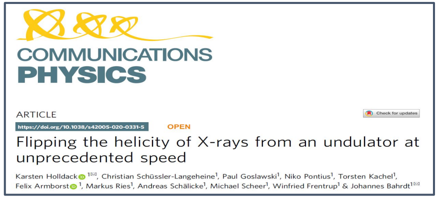

scientific reports

Check for updates

OPEN

Two-color synchrotron X-ray spectroscopy based on transverse resonance island buckets

K. Holldack[1✉], C. Schüßler-Langeheine[1], N. Pontius[1], T. Kachel[1], P. Baumgärtel[1], Y. W. Windsor[2], D. Zahn[2], P. Goslawski[1], M. Koopmans[1] & M. Ries[1]


COMMUNICATIONS PHYSICS

ARTICLE

Check for updates

https://doi.org/10.1038/s42005-020-0331-5

OPEN

Flipping the helicity of X-rays from an undulator at unprecedented speed

Karsten Holldack[1✉], Christian Schüssler-Langeheine[1], Paul Goslawski[1], Niko Pontius[1], Torsten Kachel[1], Felix Armborst[1], Markus Ries[1], Andreas Schälicke[1], Michael Scheer[1], Winfried Frentrup[1] & Johannes Bahrdt[1✉]

Valuable addition to the user case!

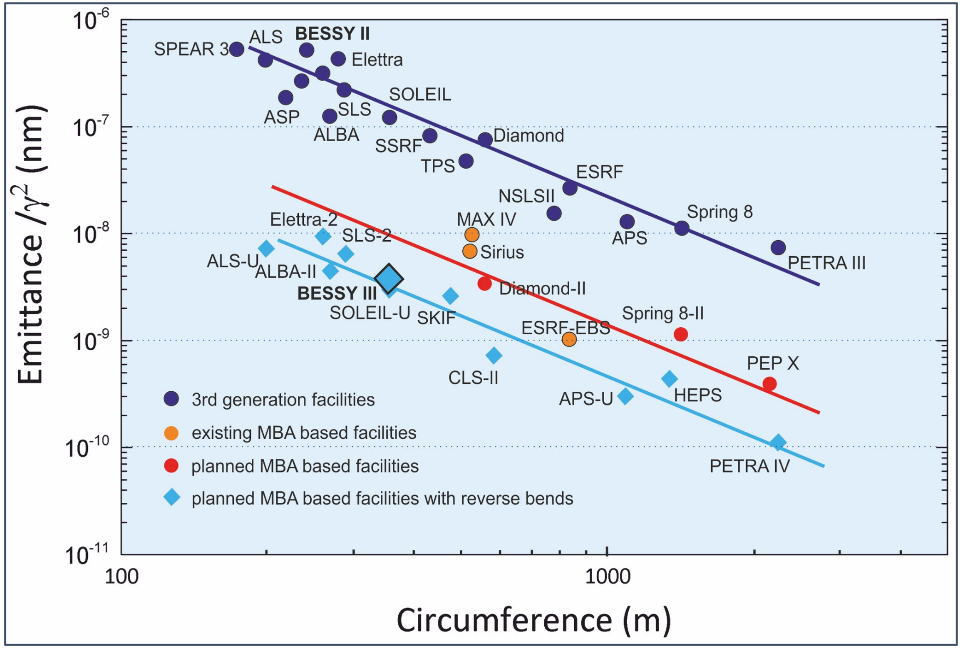
[1]M. Arlandoo, 10.18452/29179

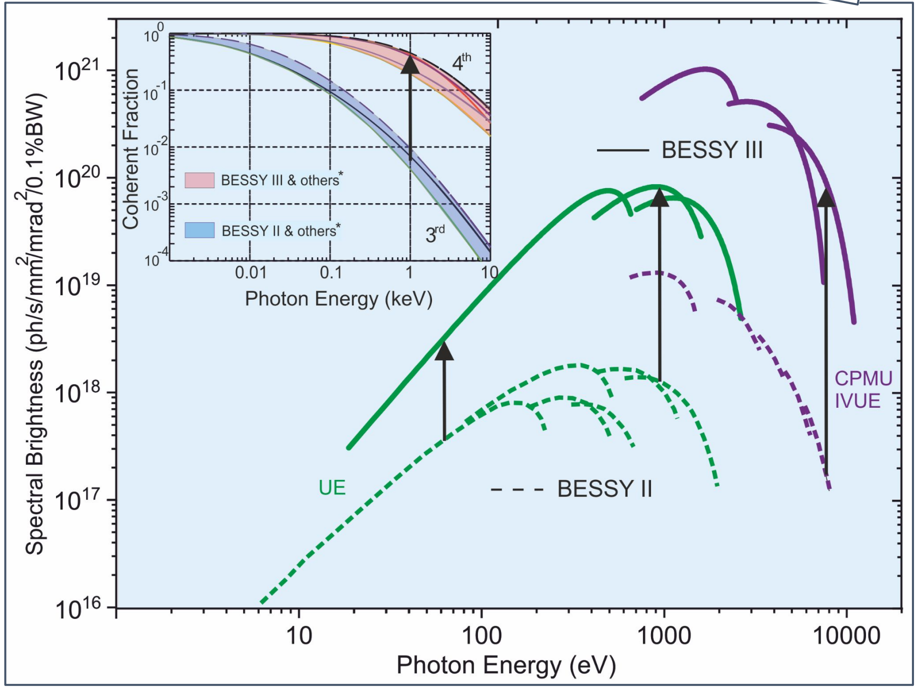
What do we have?

BESSY III Requirements & Objectives

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

BESSY III - Radiation Sources

Preliminary Beamline-Portfolio

Undulators:

- 7x 100 eV up to 2 keV (3, 4) ~ 40 mm period length
- 3x up to 10 keV (8) ~ 20-30 mm period length
- 2x up to 20 keV ~ < 20 mm period length

Bending Beamlines:

- 9x up to 2 keV (3,4)
- 4x up to 20 keV (11, 14)

Undefined

- 5 keV - 120 keV – BAMline

#	Name	Photon Energy	Main Methods	Main Applica...
1	VUV to Hard	5 eV – 20 keV	XPS, HAXPES, NEXAFS, STXM XPS, HAXPES, NEXAFS, STXM	Catalysis, ... (Storage, ...
	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	Quantum, Energy Quantum, Energy
4	Magnetic Imaging	150 eV – 2 keV	Lensless Imaging, X-ray holography, XPCS STXM, Resonant Scattering, 3D mag. tomogr.	Quantum, Energy
	DIP	100 eV – 1.5 keV	XMCD, XAS with magnetic vector fields	Quantum, Energy, Catalysis Quantum, Energy, Catalysis
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 Dynamics	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

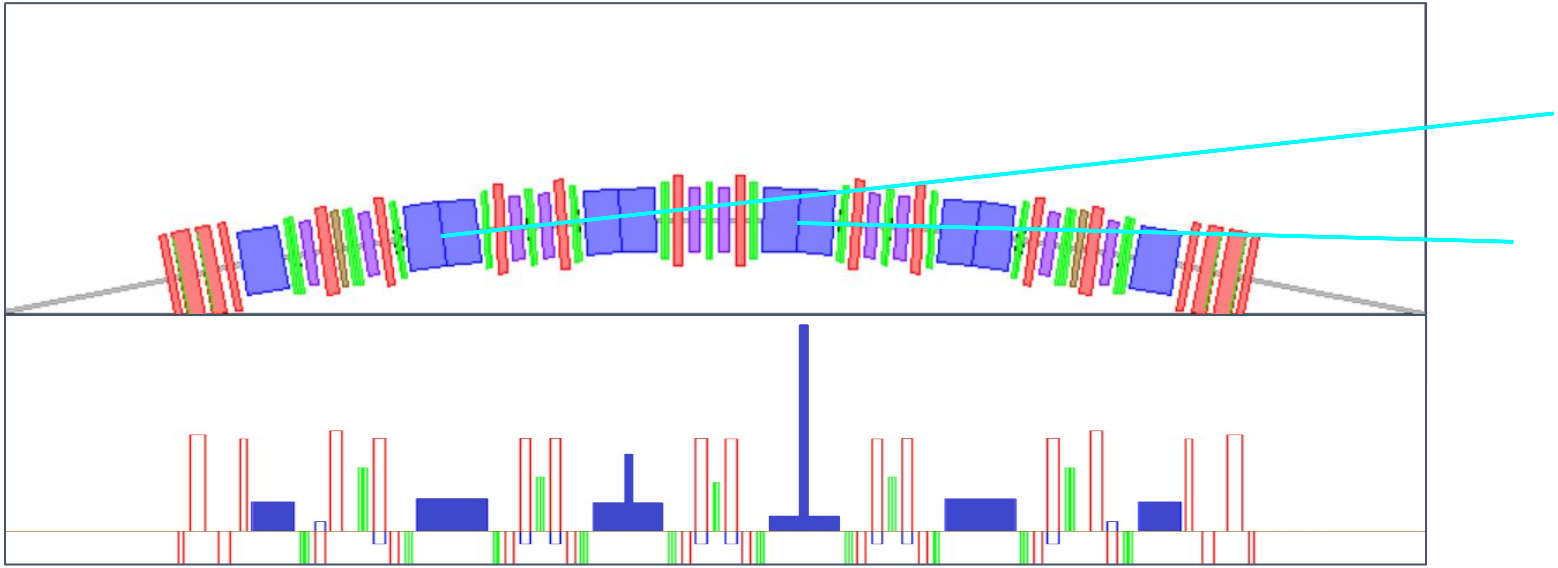
Preliminary
In progress

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 spectometry X-ray spectometry	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, µC	Materials Metrology Materials Metrology

What do we have?

Comparison of BESSY II / III - soft-to-tender X-rays (10 eV - 10 keV)

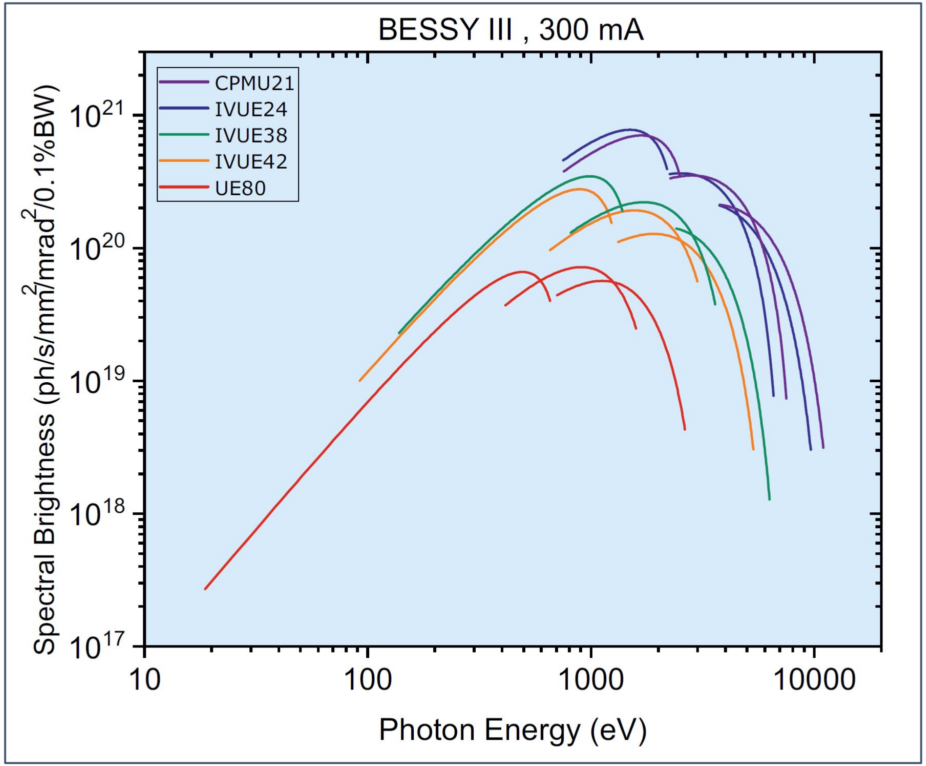
- Extract up to two bending beamlines per 6-MBA arc
- Some flexibility to adjust the critical photon energy with Longitudinal Gradient Bends (LGB)



Magnetic Field:	0.64 T	1.5 T	4 T
Critical Photon Energy:	2.6 keV	6.23 keV	16.62 keV

BESSY III - Insertion Devices:

Undulators for soft- and tender X-rays



No.	Name	Photon Energy	ID or ID combination
1	VUV to Hard	5 eV – 20 keV	UE80 + CPMU21
2	Soft and Tender	100 eV – 4 keV	IVUE 42-24 (DOPU)
3	XUV to Soft	60 eV – 1.5 keV	U70
4	Magnetic Imaging	150 eV – 2 keV	IVUE42
5	VUV Spectroscopy	5 eV – 200 eV	UE140 or UE150
6	Soft and Tender Imaging	180 eV – 8 keV	IVUE38
7	Inelastic Scattering	180 eV – 3 keV	IVUE42
8	Spectro-Microscopy	100 eV – 1.8 keV	UE56
9	Macromolecular Crystallography	5 keV – 20 keV	CPMU18
10	Multimodal Spectroscopy	20 eV – 8 keV	UE80 + IVUE24

4th Generation Lightsource Lattices

Development of Hybrid Lattice

PANTALEO RAIMONDI and SIMONE MARIA LIUZZO PHYS. REV. ACCEL. BEAMS **26**, 021601 (2023)

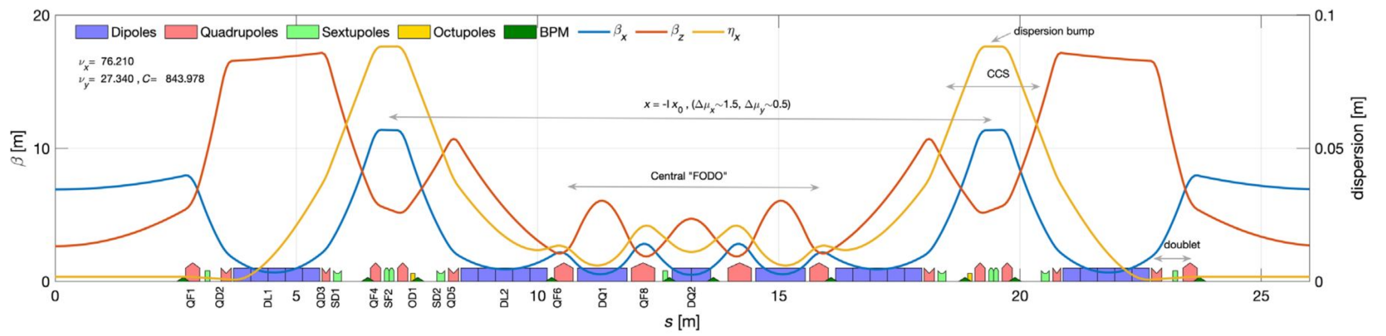


FIG. 4. Optics functions and magnet layout for the EBS H7BA cell.

TOWARD A DIFFRACTION LIMITED LIGHT SOURCE PHYS. REV. ACCEL. BEAMS **26**, 021601 (2023)

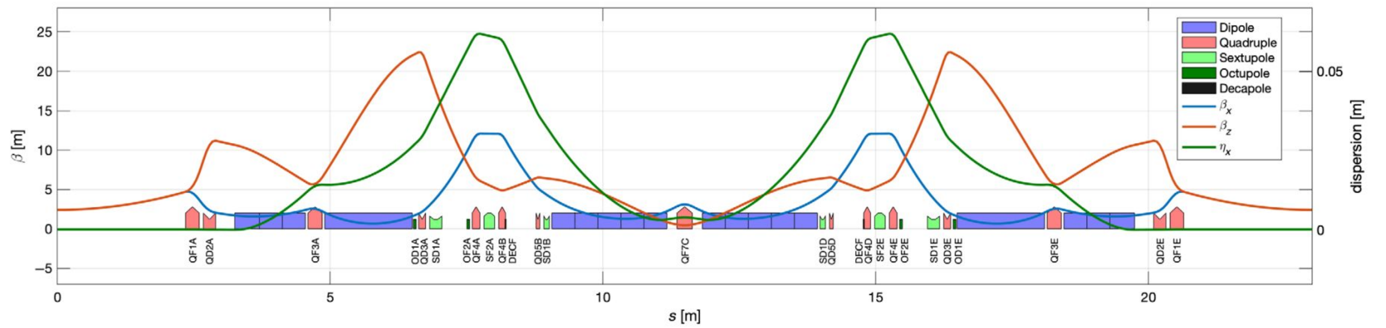


FIG. 5. Optics functions and magnet layout for an H6BA lattice cell designed for a 6 GeV, 72 cells SR lattice.

The process towards a BESSY III lattice - Linear Beam Dynamics

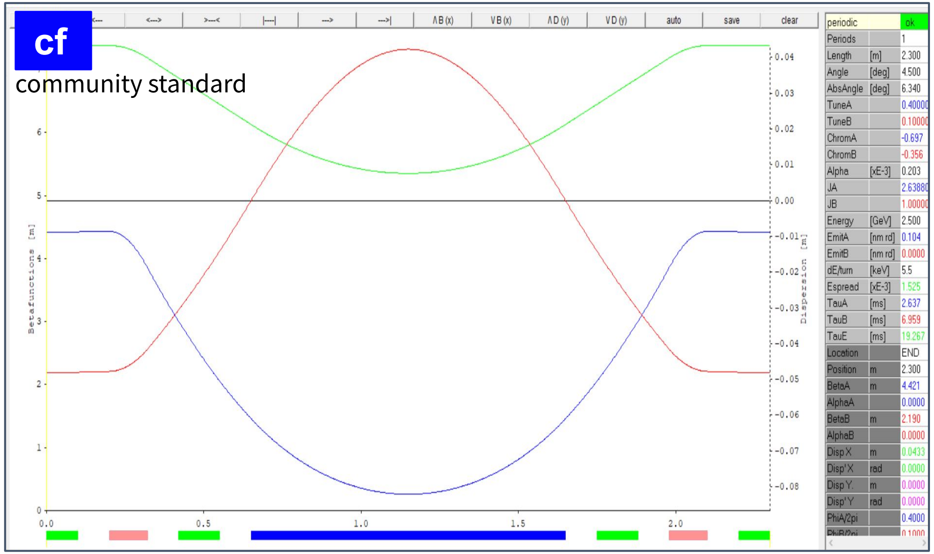
LEGO approach - the “one and only” (deterministic) MBA-Unit Cell (UC) for

and for the hardware specifications of our project

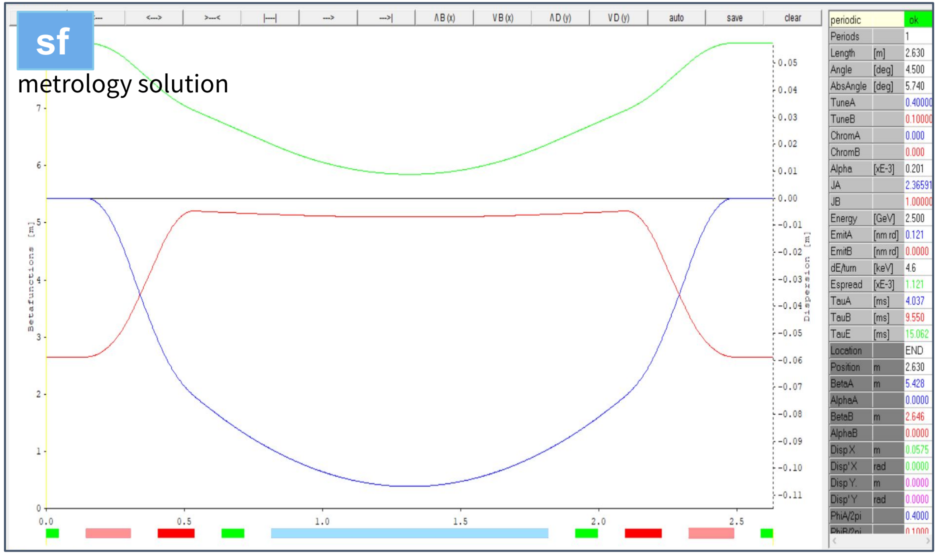
- The two different MBA-UCs: **cf & sf**
- UC (4.5°): Q_xy = (0.4, 0.1), Chrom_xy = (0.0, 0.0)

Impact of reverse bend on alpha & emittance

Magnet arrangement



SX, RB, SY, B, …



SX, RB, QD, SY, B, …

The process towards a BESSY III lattice - Linear Beam Dynamics

LEGO approach - Unit Cell - Impact of Reverse Bend

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

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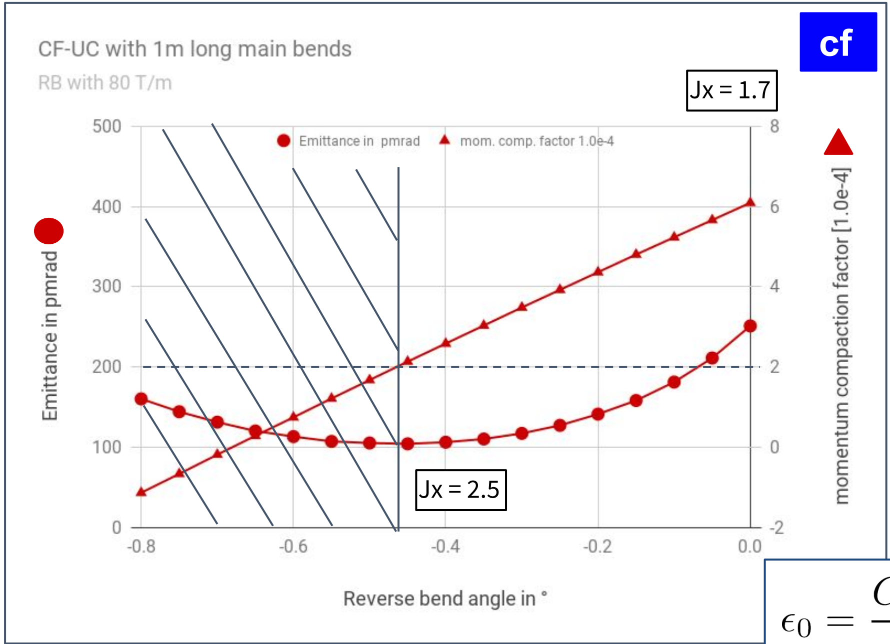
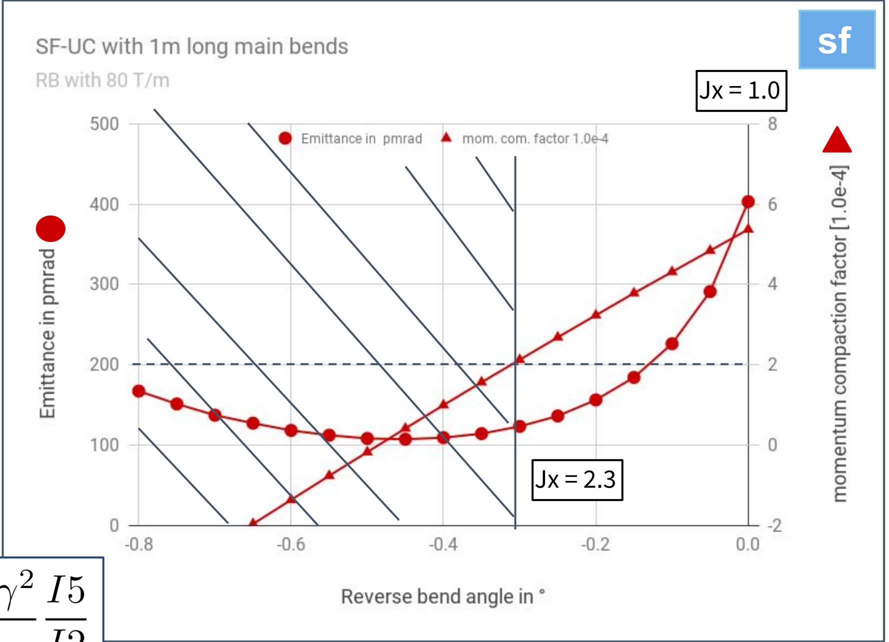




$$\epsilon_0 = \frac{C_q \gamma^2}{j_X} \frac{I5}{I2}$$

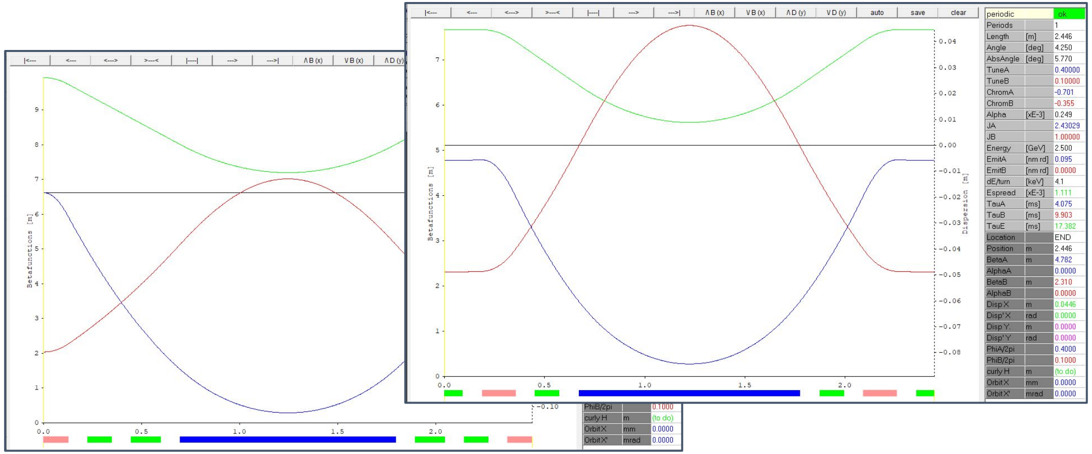
The process towards a BESSY III lattice - Linear Beam Dynamics

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:**

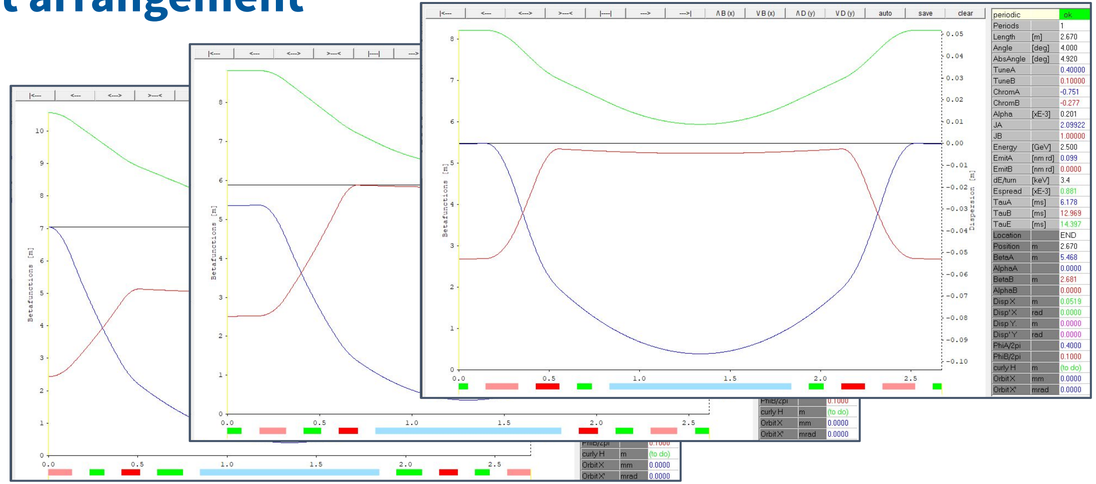


SetUp	Length	alpha	Emittance	RB angle	Nat Chrom	SUM(b3 * L)² for Chrom = 0 SF, SD [1/m²]
SX, RB, SY, B	2.446 m	2.5e-4	95 pm rad	-0.38 ° (k = 6.7) L = 0.163*2	-0.701, -0.355	**2324.77** 21.02, -26.84
RB, SX, SY, B	2.490 m	2.7e-4	95 pm rad	-0.26° (k = 6.8) L = 0.125 *2	-0.802, -0.278	**3905.21** 27.96,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

The process towards a BESSY III lattice - 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

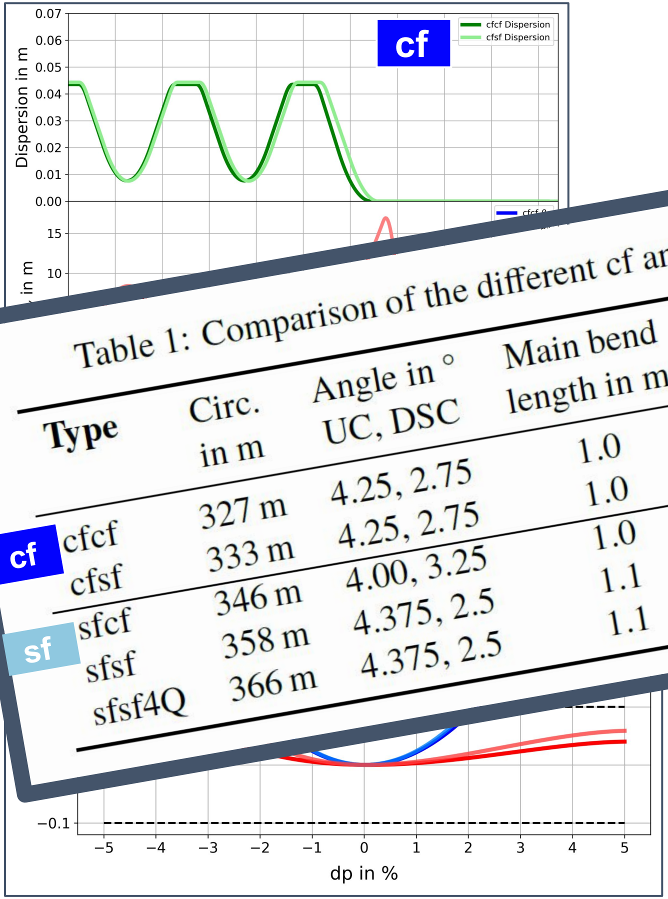


$$\xi_{tot} \sim \oint [k_2(s)\ D(s) - k_1(s)]\ \beta(s)\ ds$$

- **The 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

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



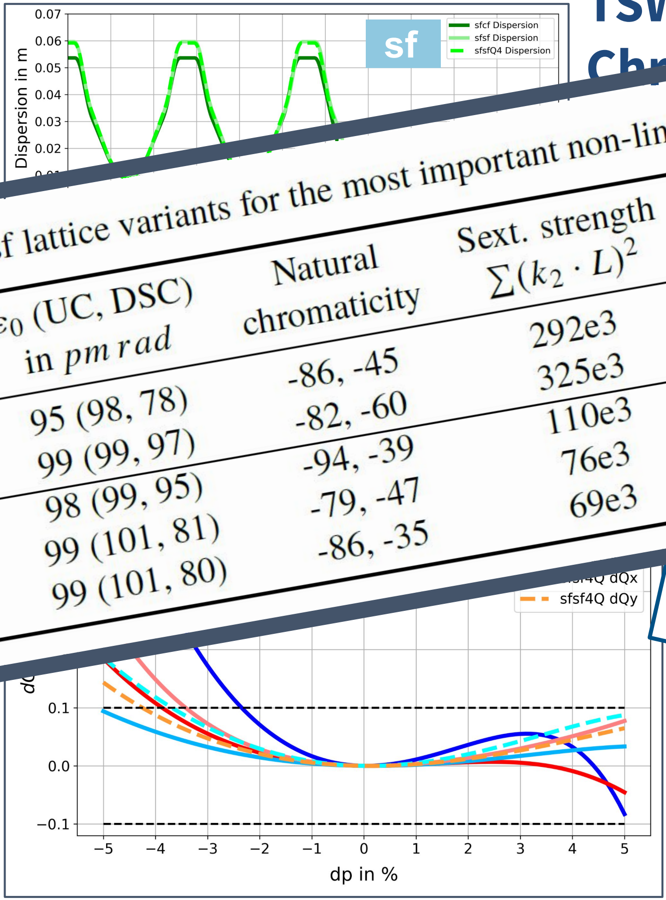


Table 1: Comparison of the different cf and sf lattice variants for the most important non-linear parameters.

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 $dQ_{x,y} = 0.1$
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
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

cf

sf

TSWM

Chro... shift

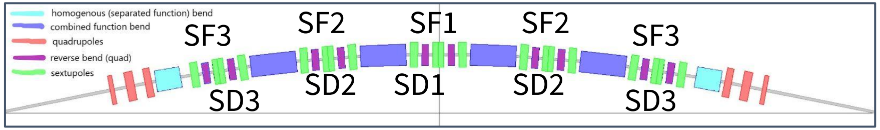
...tter the curve the better
→ Robustness, Lifetime

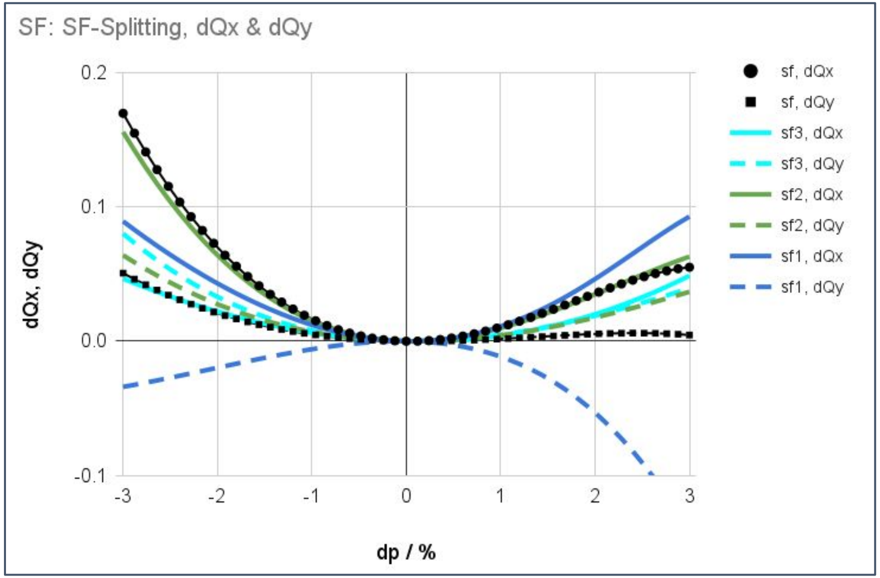
$$\frac{1}{\tau_t} = \frac{N r_e^2 c}{8\pi} \frac{1}{\sigma_x \sigma_y \sigma_s} \frac{1}{\gamma^2 \delta_{acc}^3} D(\zeta)$$

Non-Linear Beam Dynamics - Sextupole Split Up

Non-linear optimization

- 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





Alpha buckets - higher order of mom.com

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%	~ 3.0%	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 …
  - Non-linearities in the longitudinal plane limits the momentum acceptance
  - 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

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

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

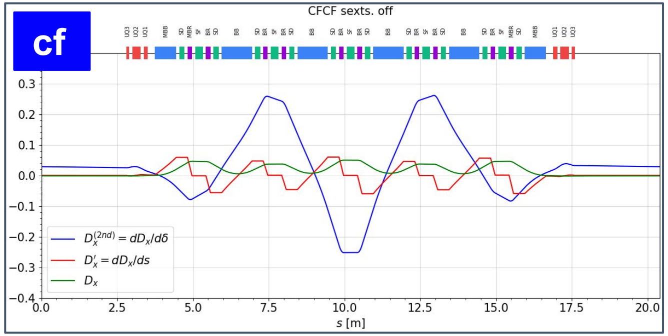
$$\alpha_0 = \frac{1}{L_0}\oint \frac{D}{\rho}\,ds \qquad \alpha_1 = \frac{1}{L_0}\oint \frac{D'^2}{2} + \frac{D_1}{\rho}\,ds$$

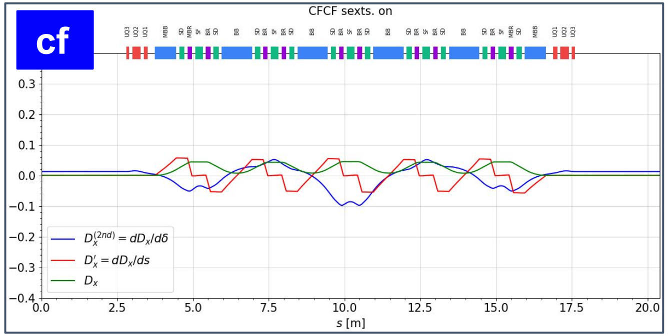
Alpha buckets - higher order of mom.com

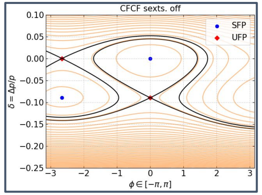
Natural Chromaticity in long. plane & Knobs for Correction (or Attack)

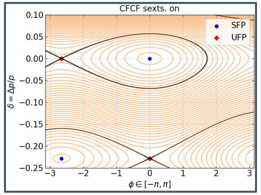
- Ratio of α_0/α_1 limits the rf momentum acceptance
- Increase α_0, reduce RB &/or lengthen main bend
- Reduce α_1, figure out what is the biggest contribution

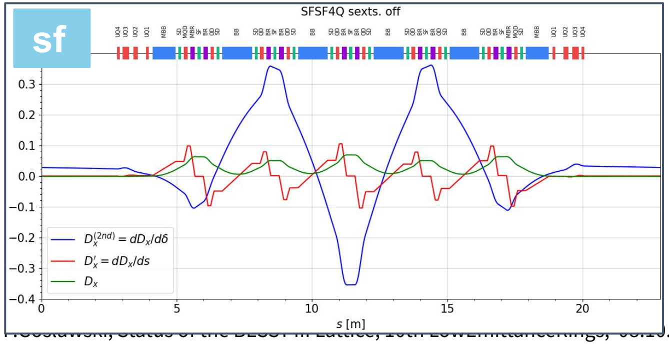
$$\alpha_0 = \frac{1}{L_0}\oint \frac{D}{\rho}\, ds \qquad \alpha_1 = \frac{1}{L_0}\oint \frac{D'^2}{2} + \frac{D_1}{\rho}\, ds$$

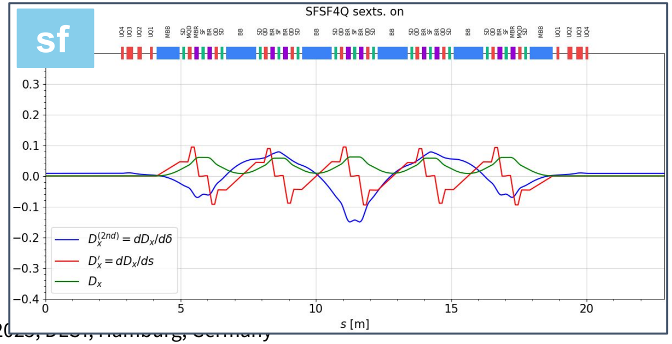












Alpha buckets - higher order of mom.com

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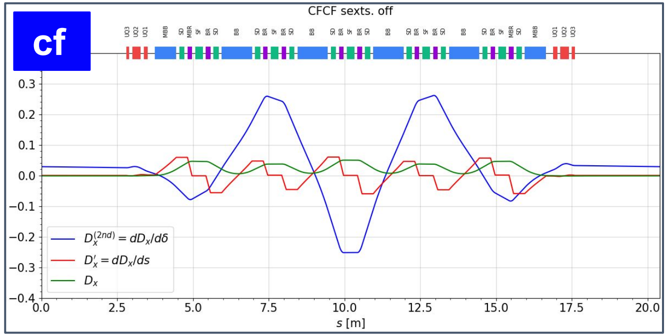
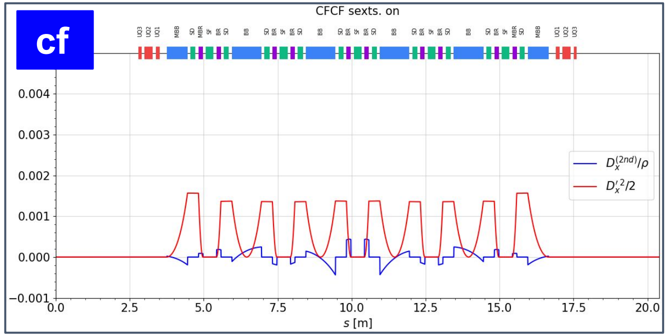
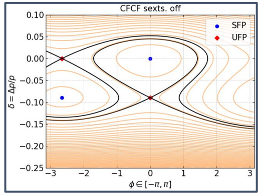
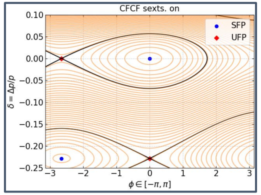
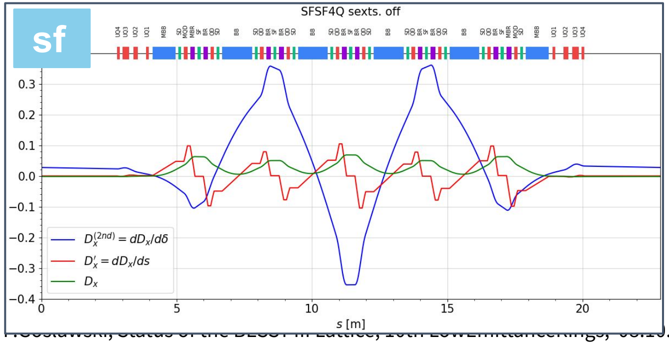
$$\alpha_0 = \frac{1}{L_0}\oint \frac{D}{\rho}\, ds \qquad \alpha_1 = \frac{1}{L_0}\oint \frac{D'^2}{2} + \frac{D_1}{\rho}\, ds$$

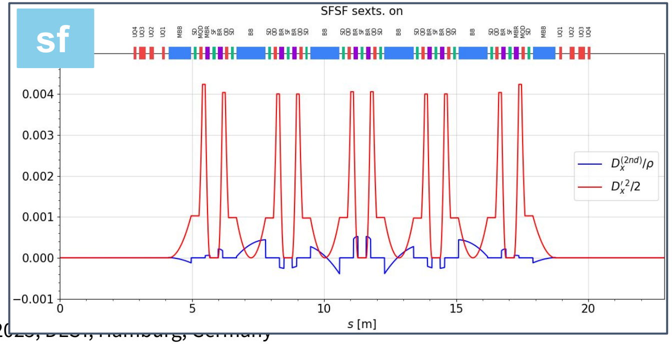












The sf-UC with the additional vertical focussing quadrupole with very good separation of beta_xy functions at the chromatic sextupoles which guarantees for good TSWM,

generates small mom. Acc. in the longitudinal plane

Longitudinal momentum acceptance

Improving the sfsf4Q lattice

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 = 0.2
sfsf4Q	4% → 5%	~ 3.5%	1.0 / 12.1 = 0.08
sfsf4Q*	4% → 5%	~ 5% - 6%	1.3 / 9.4 = 0.14

- Countermeasures to improve the momentum acceptance in the longitudinal plane:
  → Increase α_0 and decrease α_1
- Reduction of the main bending angle (4.375° ---> 4.25°) and rebalancing bending into DSC (2.5° ---> 2.75°)
  - This allowed for reducing the reverse bend angle
- Omitting the reverse bend in the DSC

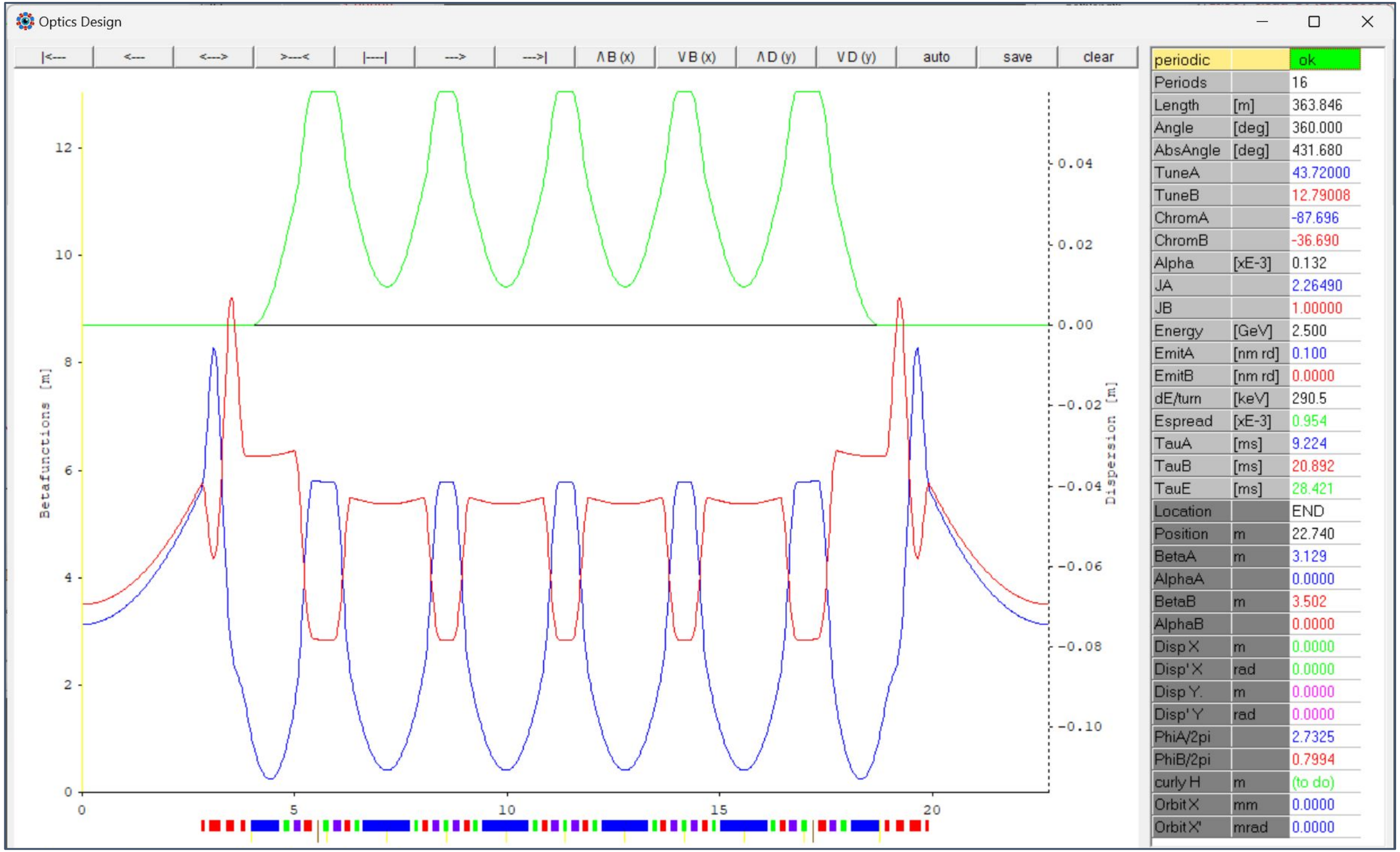
What do we have?

A lattice for the CDR/TDR phase

Baseline lattice

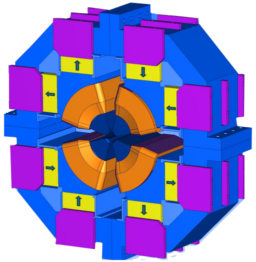
Circ.:	C = 360m
Energy:	E = 2.5 GeV
Straights:	16
# bunches:	~ 600
Zero Current Emittance:	ϵ_x = 100 pm rad
Zero Current Bunch Length:	8-10 ps (rms)
momAcc:	4-5%
Touschek LT:	> 5 h
300 mA, 2% coupling	

All numbers for a **bare lattice**.

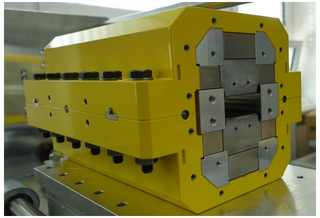


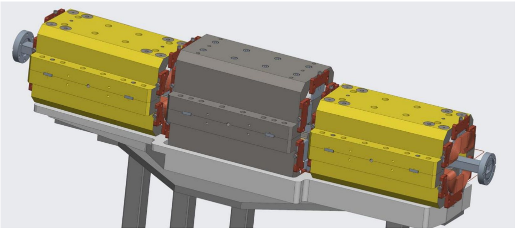
What do we have?

Courtesy: **Jens Völker**



First design idea for magnets

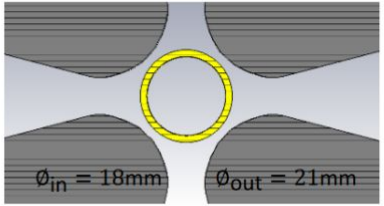




Towards a combination of permanent & electro magnets

	Dipole	Quadrupole	Reverse Bends	Sextupole
Field/gradient	0.6-0.8 T	50-90 T/m	80 T/m + 0.18-0.22 T	<4000 T/m²
Quality	$0.1 \cdot 10^{-4}$	$\sim 1 \cdot 10^{-4}$	$\sim 1 \cdot 10^{-4}$	tbd
Stability	$<1 \cdot 10^{-4}$			
Variation	-	10%	5%	100%
Power consumption (PM / electro)	0 kW / 290 kW	<25 kW / ~600 kW		>100 kW

min. aperture radius for all magnets: 12.5mm



	BESSY III conventional	BESSYIII PM
96 Dipoles	ca. 290 kW	0 kW
446 Quadrupoles	ca. 600 kW	< 25 kW
NL Multipoles (**240** Sextupoles, **32** Octupoles)	ca. 130kW	
Total	**ca. 1000 kW**	**ca. 150 kW**

1. Strong magnetic fields -> high magnetic field energy / **electric power**
2. High field Quality -> high mechanical and alignment precision
3. Stable field operation -> minimization of ripple and vibrations
4. Small parameter Variation -> constant magnet operation next to design value

What is going on?

Courtesy: **Sven Lederer**

Pushing the lattice towards technical design