HZB BESSY II Light Source

BESSY III Status

& Accelerator Software (Requirements)

P. Goslawski for the HZB accelerator team

2nd Accelerator Middle Layer Workshop, Feb2025, HZB, Berlin, Germany

Accelerator software & non-linear beam dynamics

Overview

- Goal → long-term project … a Future ?!
- What do we have ? → pre-CDR, a first concept
  - One bare lattice (two, three, four, …, conceptional)

    → initial nonlinear beam dynamics
- What is next / What is going on ?
  - One real technical lattice - A simulated commissioning lattice

    → TDR, tendering, real machine
- Outlook

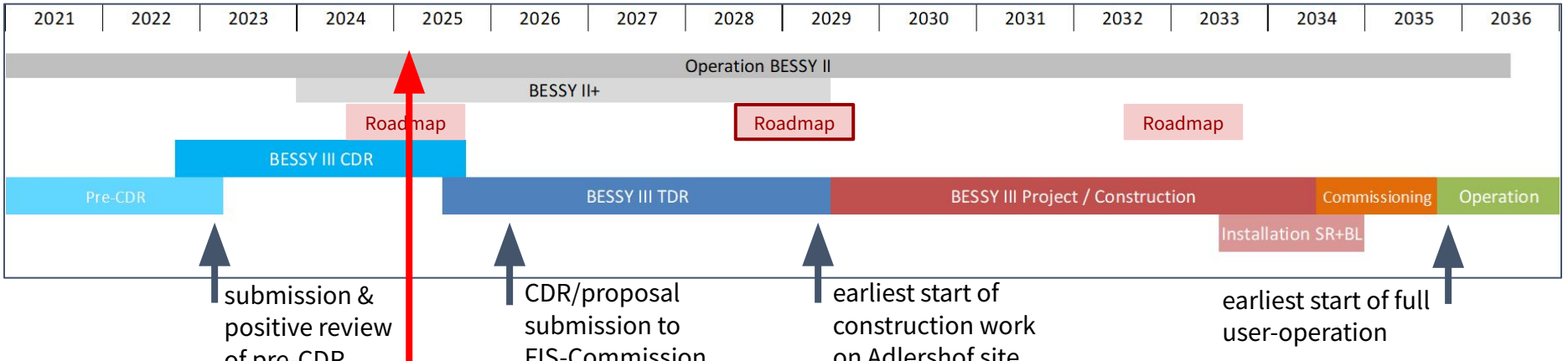
Goal

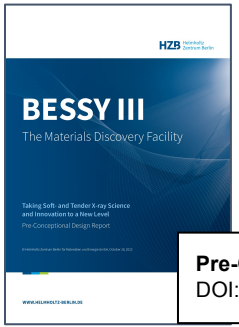
Greenfield 2035

The Path to the Goal

Digital Workflows

Courtesy: **Markus Sauerborn**





Pre-CDR
DOI: 10.5442/r0004

Greenfield: "No" limitations of an existing facility

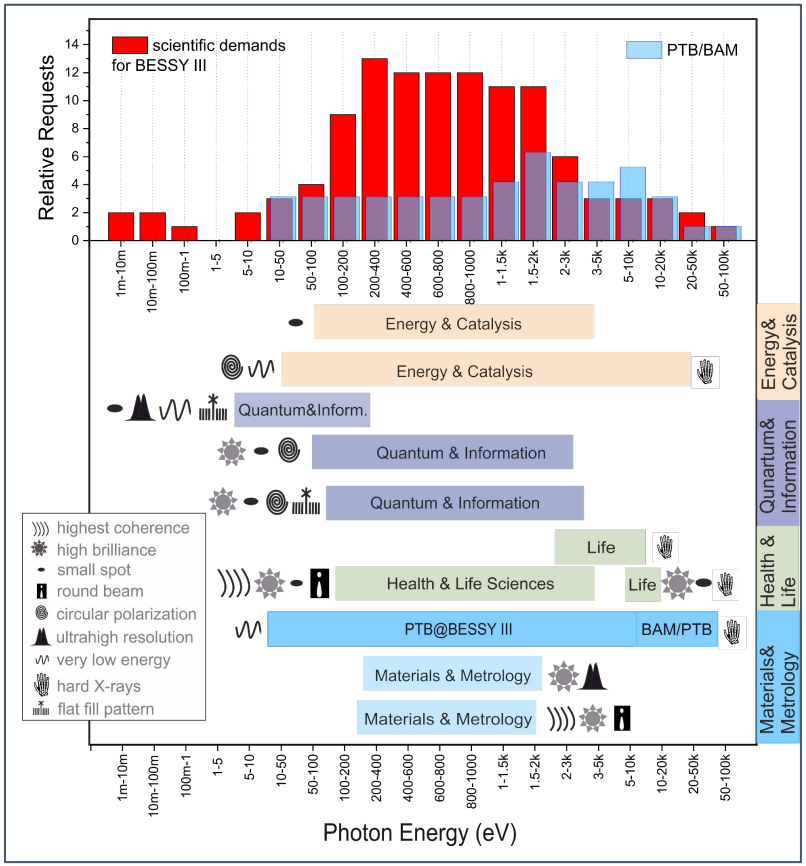
2035: Long project duration

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)**

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**

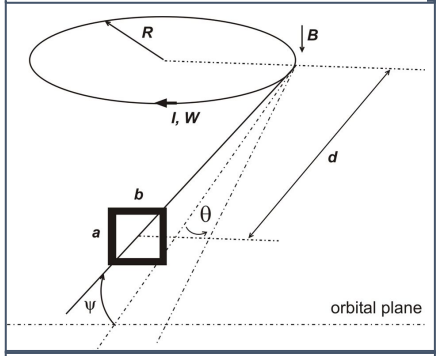
Already at BESSY II, a 3rd generation **without** combined function bends

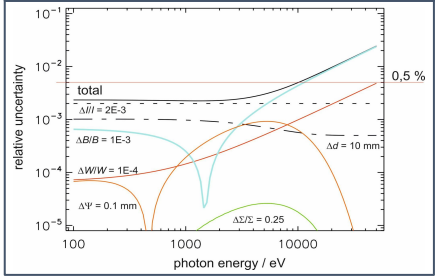
What do we have?

Stability

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

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





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

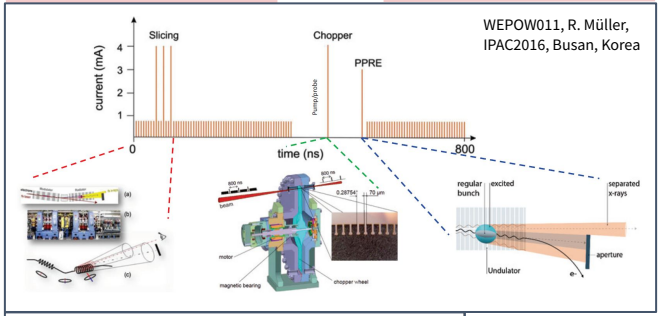
$$\frac{1}{\tau_t} = \frac{N\, r_e^2\, c}{8\pi} \frac{1}{\sigma_x\, \sigma_y\, \sigma_s} \frac{1}{\gamma^2\, \delta_{acc}^3} D(\zeta)$$

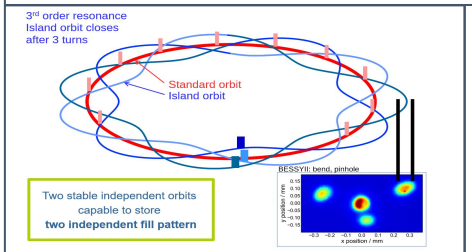
$$Q = Q(\delta, J_{x,y}), \qquad \delta = \Delta p / p_0$$

Objectives for Lattice Design

Flexibility

Timing modes
Short pulses
Repetition rate





Low **α** &
sc or **nc VSR**

COMMUNICATIONS PHYSICS

ARTICLE

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

scientific reports

OPEN

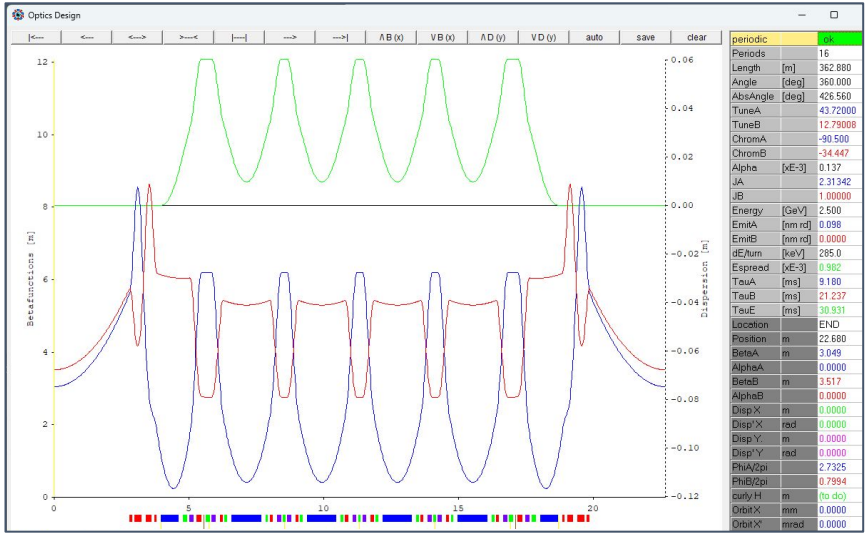
Two-color synchrotron X-ray spectroscopy based on transverse resonance island buckets

What do we have?

Courtesy: **B.Kuske, J.Bengtsson, M.Abo-Bakr**

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

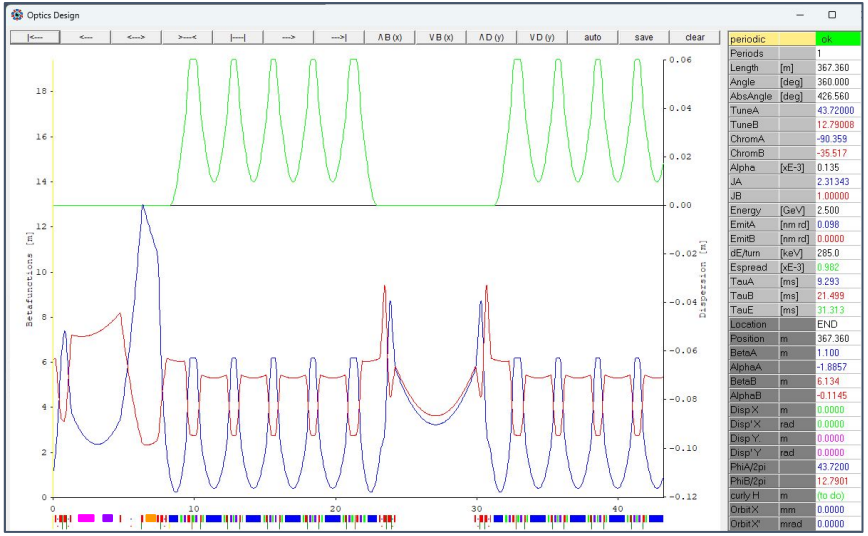
- Pure fundamental lattice - periodic sector cell:
  Only big beam guiding elements: bends, quads, sexts
- Only two sextupole families (SF, SD) to correct natural chromaticy → start of non-linear dynamics



Simulated Commissioning Lattice

Real Technical Lattice

- Perturbing the periodic sector cell:
  Injection straight & straight ID adaption
- Robustness analysis: Misalignments, SC
  Correction Schemes: Orbit Correction (BPMs & Corr.), ..



What do we have?

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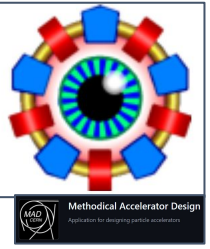
OPA
Lattice Design Code



Software for Accelerator Design

Simulated Commissioning Lattice
Real Technical Lattice

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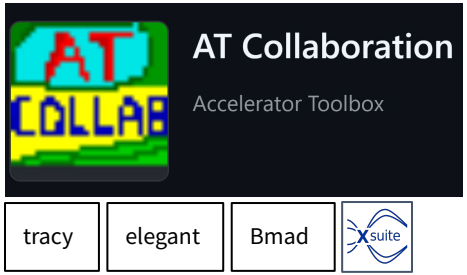
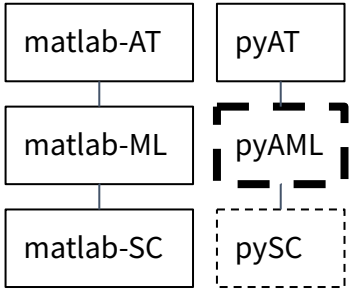




Software for Accelerator Realisation/Operation

What do we have?

Bare Lattice(s)

(HOA, hybrid not studied yet)

- Pure fundam
  Only big bear
- Only two sext
  chromaticy →

Simulated Commissioning Lattice

Real Technical Lattice

ll:
aption

nts, SC
ction (BPMs & Corr.), ..

Very personal statement:

For me it seems that the process of coming from a

bare lattice to a technical lattice

is somewhat broken !

Examples:

- Robustness analysis - How many lattices break when including misalignments
  (J. Bengtsson - Robustness analysis: SLS, NSLS-II, Diamond → RDT)
- PETRA IV Lattice: First scaled/adapted ESRF-Hybrid 7MBA
  (R. Pantaleo) → NewHybrid 6MBA
- SLS2.0 Design process: negative/low alpha
  (A. Streun)

Do we understand non-linear beam dynamics!?

OP
Lattice D
Code

natlab-AT
natlab-ML
natlab-SC

pyAT
pyAML
pySC

Software f

lerator
ation

Bare Lattice

What do we have?

Bare Lattice(s)

Methodical Accelerator Design

OPA
Lattice Design Code

- Why is OPA so successful?
- Wiki - Accelerator Codes -
  - “Only” Single Particle Dynamics
  - But it gives you a unique lattice crafting/design experience

It’s like crafting a lattice with your bare hands!

Direct response!

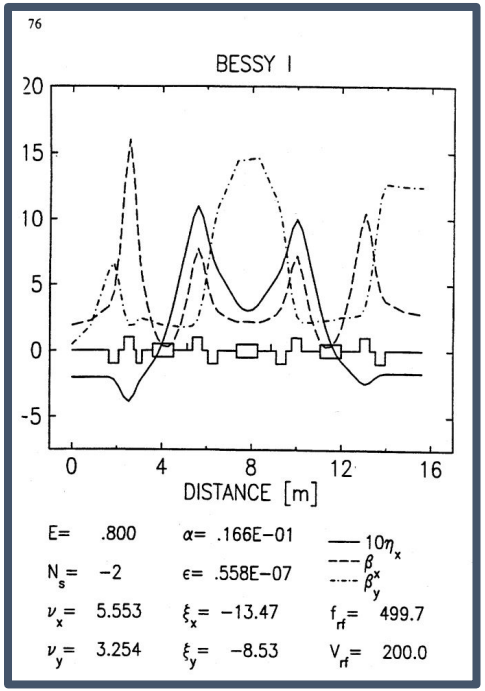
	Single Particle Dynamics	Spin Tracking	Taylor Maps	Weak-Strong Beam-Beam Interaction	Electromagnetic Field Tracking	Higher Energy Collective Effects	Synchrotron Radiation Effects	Radiation Tracking	Wakefields	Extensible	Notes
Accelerator Toolbox (AT),[6]	Yes	Yes[7]	No	No	No	Yes	No	No	No	Yes	
ASTRA[8]	Yes	No	No	No	Yes	Yes	No	No	Yes	No	For space-charge simulations
BDSIM[9]	Yes	No	No	No	Yes	No	No	No	No	Yes	For particle-matter simulations.
Bmad (contains PTC)[10]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Reproduces PTC's unique beam line structures. Simulates X-rays.
COSY INFINITY[11]	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Arbitrary-order differential-algebraic transfer maps
DYNAC[12]	Yes	No	No	No	No	No	No	No	No	No	
Elegant[13]	Yes	No	No	No	Yes	Yes	Yes	No	Yes	No	
MAD8 and MAD-X (includes PTC)[14]	Yes	No	Yes	Yes	No	No	Yes	No	No	No	
MAD-NG[14]	Yes	No	Yes	Yes	No	No	Yes	No	No	Yes	Extensible, embeds LuaJIT
MERLIN++[15][16]	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Other: beam-matter interactions, sliced-macroparticle tracking
OCELOT[17]	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	
OPA[18]	Yes	No	No	No	No	No	No	No	No	No	
OPAL[19]	Yes	No	Yes	No	Yes	Yes	No	No	Yes	Yes	runs on laptops and on x 10k cores.
PLACET[20]	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	LINAC including wakefields simulations.
Propaga[21]	Yes	No	No	No	No	No	No	No	No	Yes	
PTC[22]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	
SAD[23]	Yes	No	No	Yes	No	Yes	Yes	No	Yes	No	
SAMM[24]	Yes	Yes	No	No	No	No	No	No	No	No	
SixTrack[25]	Yes	No	Yes	Yes	No	No	No	No	No	No	Can run on BOINC
Zgoubi[26][27]	Yes	Yes	No	No	Yes	No	Yes	No	No	Yes	

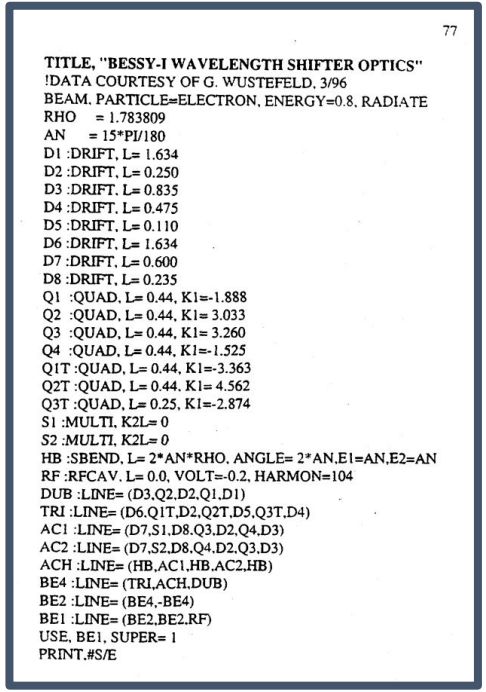
What do we have?

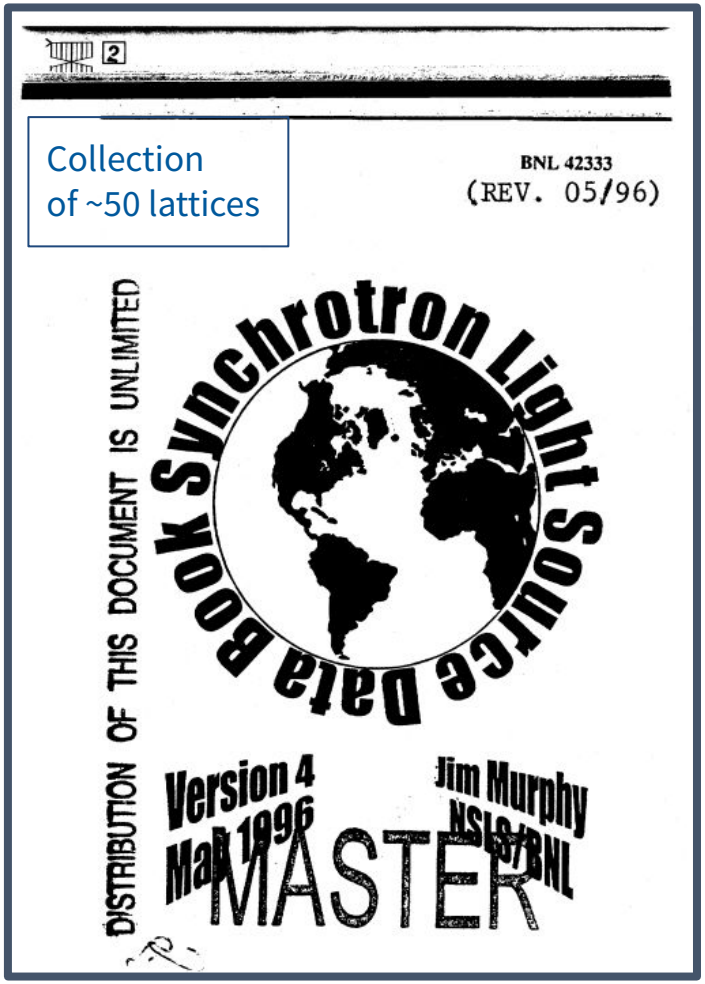
Bare Lattice(s)

OPA
Lattice Design Code

Methodical Accelerator Design
Application for designing particle accelerators







What do we have?

Courtesy: **F.Andreas**

Bare Lattice(s)

OPA
Lattice Design Code

Methodical Accelerator Design
Application for designing particle accelerators

Digital Workflows

NoBeam

5 followers · https://github.com/nobeam

Overview · Repositories 12 · Projects · Packages · People 1

Pinned

lattice-summaries Public
Framework to generate comparable summaries for different lattice files.
Python ☆ 1

lattice-summaries-website Public
Frontend to display data generated by lattice-summaries.
Vue ☆ 2

latticejson Public
A JSON based lattice file format
Python ☆ 12 ⑂ 2

eleganttools Public
Python tools for post processing elegant simulation data
Python ☆ 1

People

Top languages
Python · Nix · Vue

Lattice Summaries

Summary of BESSY II Design Lattice 1996

Data is generated by apace

BESSY II Design Lattice 1996
bessy2/bessy2_design-1996_v_1
by HZB
Fully symmetric Design Lattice of the BESSY II storage ring (Here as reference and to test stuff!)

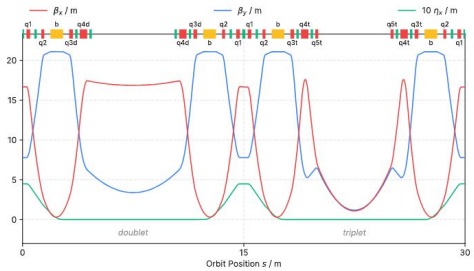
Lattice files: json · lte · madx

Summaries: apace · elegant · madx

Lattice Info

PARAMETER	VALUE
Energy / MeV	1.70e+3
Circumference / m	240
Fully symmetric	1.00
Number of sections	8.00
Section length / m	30.0
Bends per section	4.00
Reverse bends per section	0.00

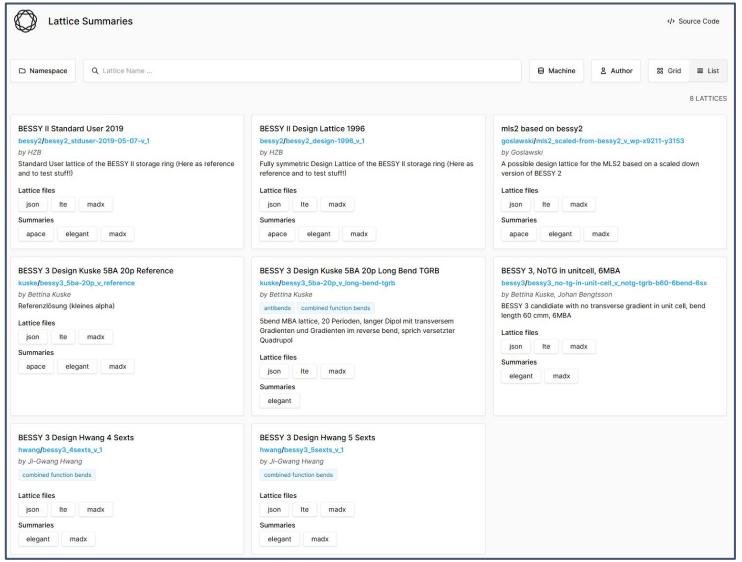
Optical Functions



Detailed Lattice Parameter

PARAMETER	VALUE	PARAMETER	VALUE
Q_x	17.8	Q_y	6.74
$\beta_{x,max}$ / m	17.6	$\beta_{y,max}$ / m	21.1
$\beta_{x,min}$ / m	0.301	$\beta_{y,min}$ / m	1.19
$\beta_{x,mean}$ / m	8.55	$\beta_{y,mean}$ / m	10.8
$\eta_{x,max}$ / m	0.450	$\eta_{y,max}$ / m	0.00

PARAMETER	VALUE
Mom. compaction	0.000732
Emittance	5.13e-9
I_1	0.176
I_2	1.44



Real Lattice

What is next/going on?

Courtesy: **S.Joly**

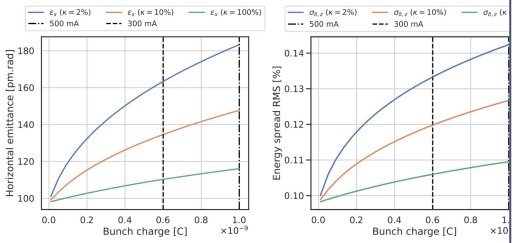
Real Technical Lattice, Simulated Commissioning

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

In progress

Emittance blow-up in BESSY III

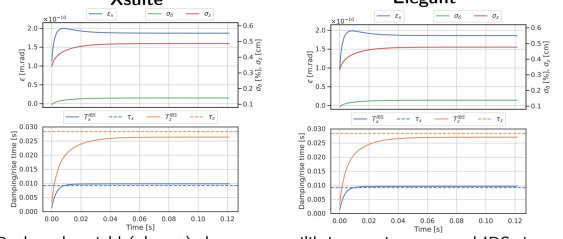
Assuming the following zero-current parameters: $\varepsilon_{x,0} = 10^{-10}$ [m.rad] $\sigma_{\delta,0} = 9.8 \times 10^{-4}$, $\sigma_{z,0} = 3.5 \times 10^{-3}$ [m]



Increasing κ substantially decrease the magnitude of the IBS induced emittance blow-up.

Comparison Elegant/Xsuite

The equilibrium emittance differential equation can be solved numerically Already existing tool in Elegant (ibsEmittance[5]) but no preexisting one in Xsuite → I have implemented my own.

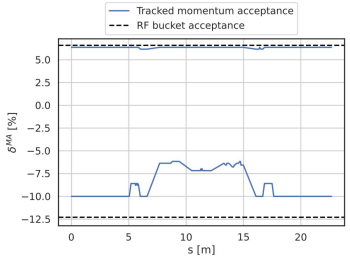


Both codes yield (almost) the same equilibrium emittances and IBS rise times!

[5] ibsEmittance documentation

Determination of the momentum acceptance

The momentum acceptance δ_{MA} is defined as the largest δ value for which a particle with starting coordinates (0, 0, 0, 0, $\pm\delta$, 0) is stable after a given number of turns[7].

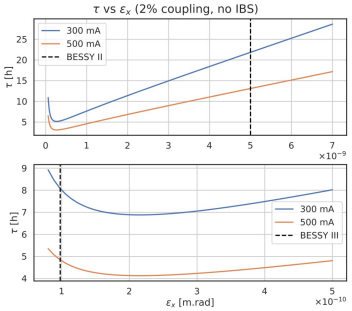


Asymmetry caused by the ratio $\frac{\alpha_1}{\alpha_0} > 1$.

For $V_{RF} = 1$ MV and without magnets' misalignments/errors, the MA is equivalent to the RF bucket momentum acceptance .

[7] M. Belgroune

Touschek lifetime regimes

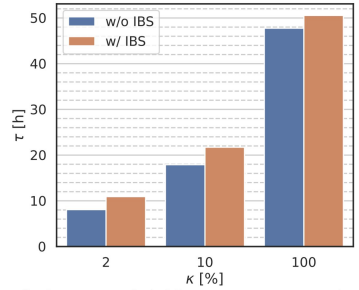


BESSY II (uniform filling scheme) in parameter area where $d\tau/d\varepsilon_x > 0$

BESSY III in parameter area where $d\tau/d\varepsilon_x < 0$

⚠ Need to be careful with effects increasing $\varepsilon_x \rightarrow$ IBS

Impact of IBS on Touschek lifetime



- IBS increases $\varepsilon_x \rightarrow \tau$ decreases
- IBS increases $\sigma_z \rightarrow \tau$ increases
- Overall gain in lifetime as stronger dependency with σ_z than with ε_x.

All above Touschek lifetime were computed with a 300 mA current.

What is next/going on?

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

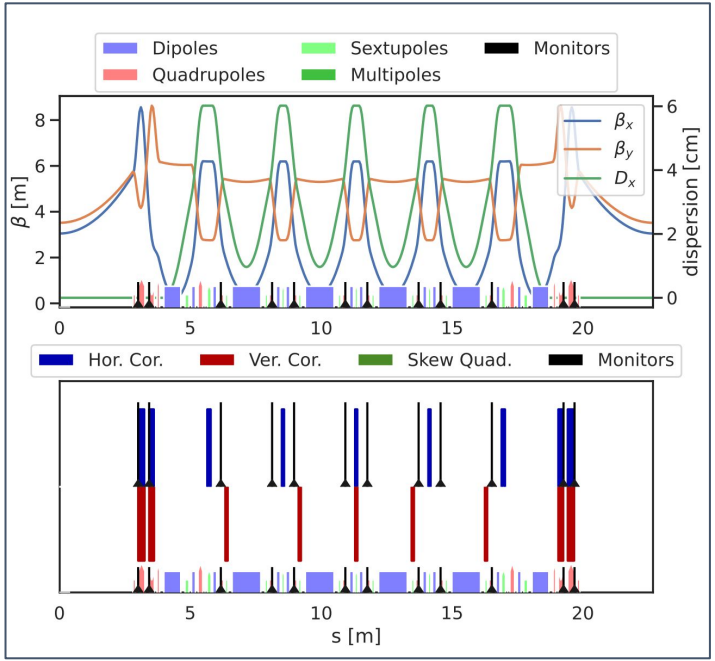
Real Technical Lattice, Simulated Commissioning

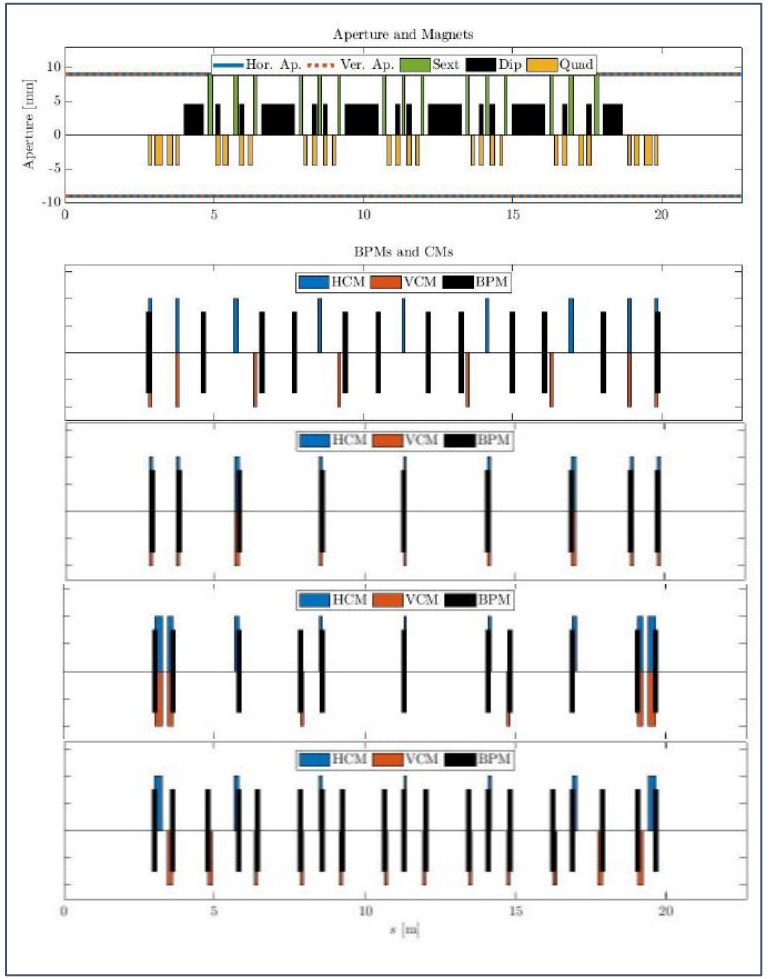
In progress

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

  AT Collaboration
  Accelerator Toolbox

  (elegant, opa)





What is next/going on?

Courtesy: **B.Kuske, M.Arlandoo**

Real Technical Lattice, Simulated Commissioning

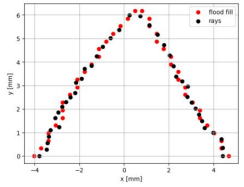
- **Non-linear setup - optimisation in both planes: transversal & longitudinal**
- **Optimization of non-linear aspects (TSWA, TSWM)**
  - Analysis & reduction of resonance driving terms
  - MOGA - multi objective generic optimisation
- **Sextupole split up and higher order multipole mags:**
  → chromatic octupoles
  → harmonic/geometric sextupoles & octupoles
  with pyAT-SC, matlabAT-SC, elegant
  - Flood fill algorithm for fast DA calculation (SLS - J .Kallestrup)
    https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.27.094002
  - What are our measures?

In progress

TRACKING ALONG RAYS ⇔. FLOOD FILL

Comparison of tracking along rays (red) and flood fill (black)

- Baseline lattice Sept2024
- 512 turns
- Ray tracking: 40 rays, 20 points each
  => 40 points on boundary
- Flood fill: grid: -5mm<x<5mm, y<6.5mm, spacing 0.32mm
  => 40 points on boundary



Why flood fill?

- Tracking of full no. of turns only on boundary
- Example above:
  Rays: tracks 568 stable particles
  FF: tracks 40 stable particles
- Finds islands
- Draw back: flood fill scales poorly with no. of CPUs
- But very attractive run time on laptops

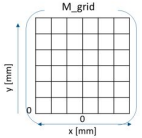
Athena CPU [sec]	Rays	Flood fill 4 start point
1	121.74	11.64
2	62.53	9.00
4	34.4	8.44
8	19.41	7.10
16	10.42	6.33
32	5.53	6.81
64	3.48	6.74
128	2.5	6.83

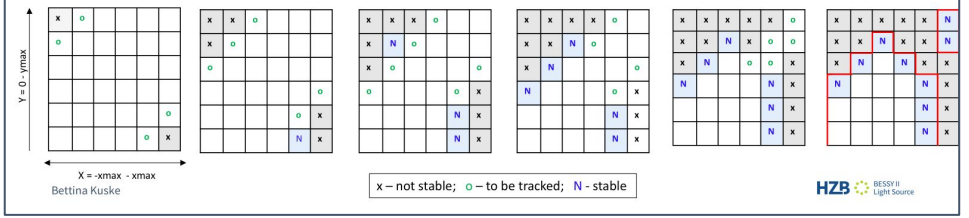
MOGA – FLOOD FILL

MOGA – tracking with flood fill algorithm

Flood fill Ref: *Efficient algorithms for dynamic aperture and momentum acceptance calculation in synchrotron light sources, Bernard Riemann , Masamitsu Aiba , Jonas Kallestrup , and Andreas Streun, PRAB 27, 094002 (2024)*

- Define grid matrix (covering DA) and control matrix
- Define a queue to store points to be tracked next, enter one or more starting points
- Track first element in queue
  - If **unstable**, add neighboring grid points to be tracked next
  - Store the last stable turn in control matrix
  - Delete tracked element in queue



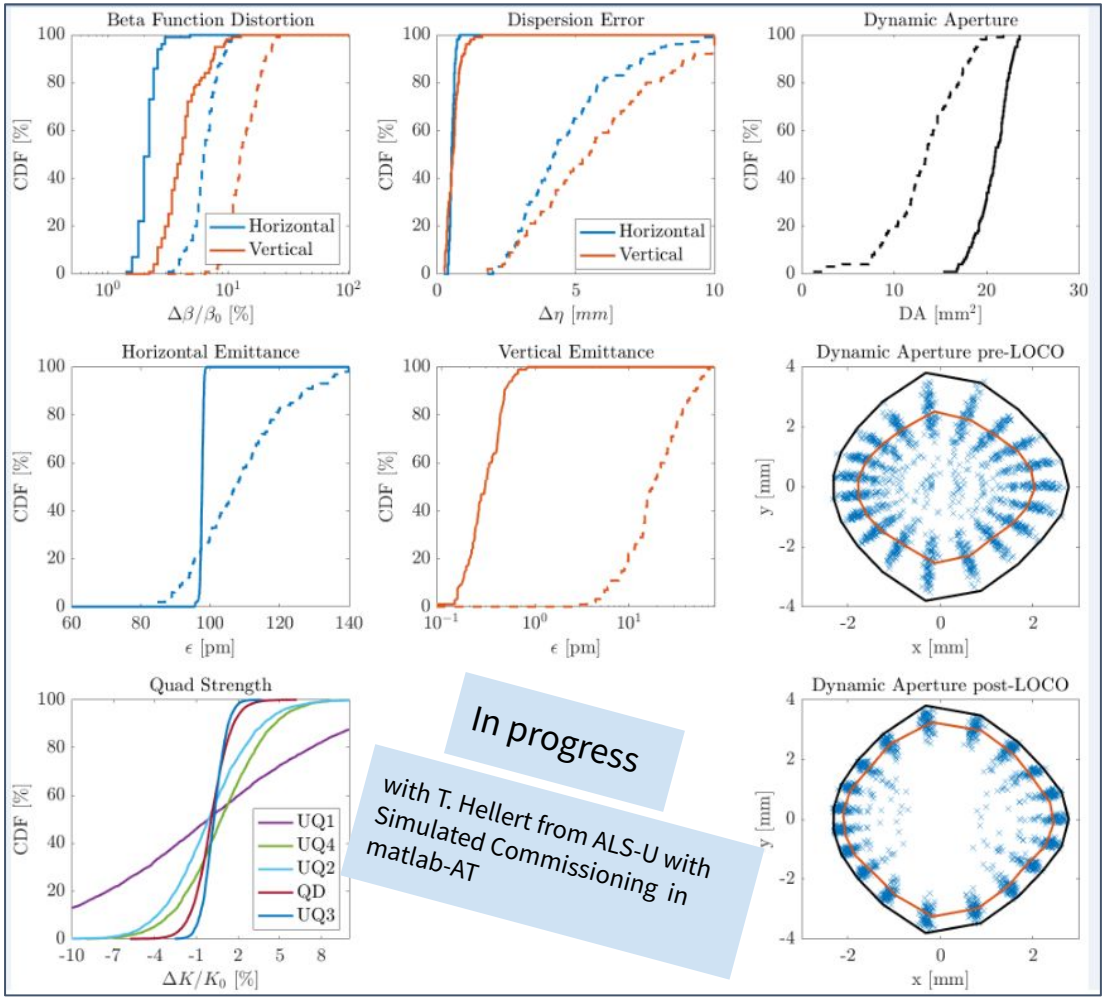


What is next/going on?

Courtesy: **T.Hellert**

Real Technical Lattice, Simulated Commissioning

- SC with matlab-AT-SC (T.Hellert)
- SC with pyAT-SC (L. Malina)



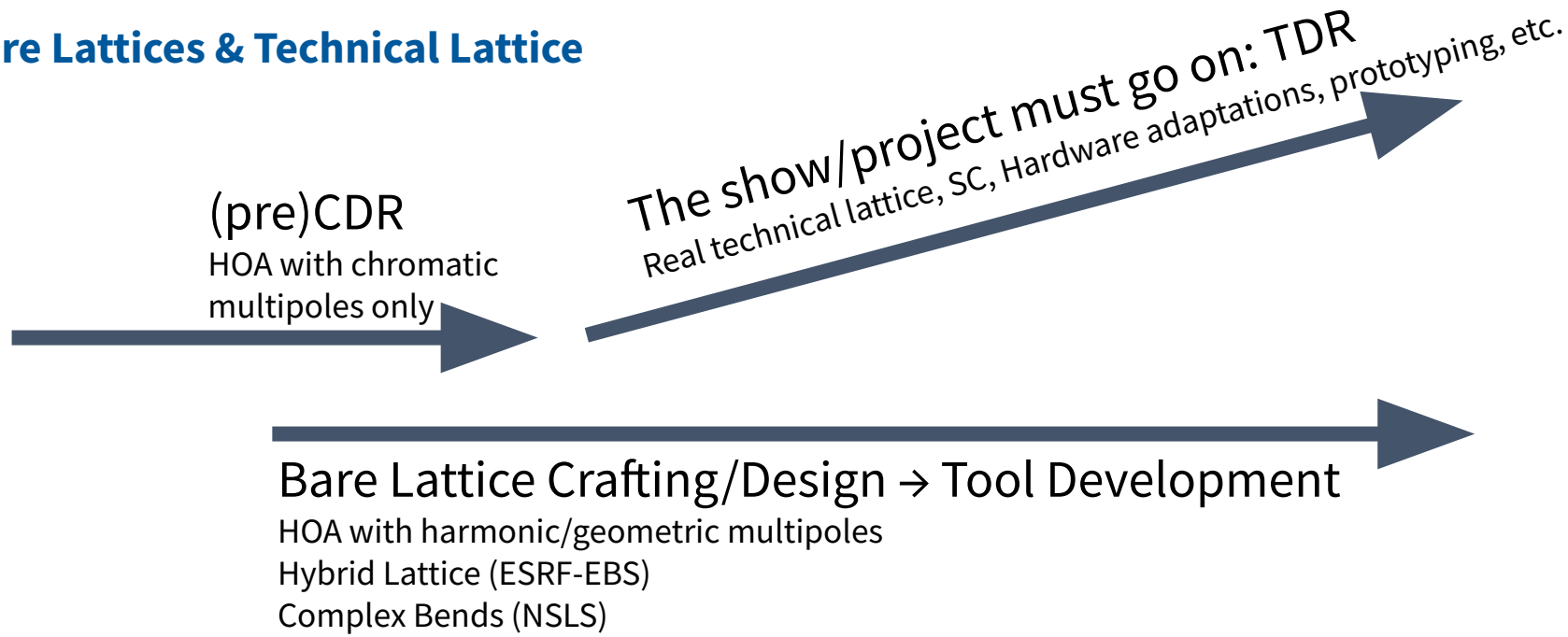
In progress

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

Outlook

Outlook

Bare Lattices & Technical Lattice



Outlook

Software & BESSY III

Digital Workflows

OPA
Lattice Design Code

madx, elegant

pyAT, pySC, pyAML
matlab-AT-SC, mml
elegant

Xsuite | mbtarck

Epics,
Tango

PTC Creo (CAD) Parametric

CST

Ansys

SynRad | MolFlow+

Fluka

SAP

Data Managment System
Administration/Project Manag.:
Specification, Reviews,
PLM (Product Lifecycle Mang.)
Purchase, Finance, Controlling,...

Thanks for your attention!