Status of the Metrology Light Source

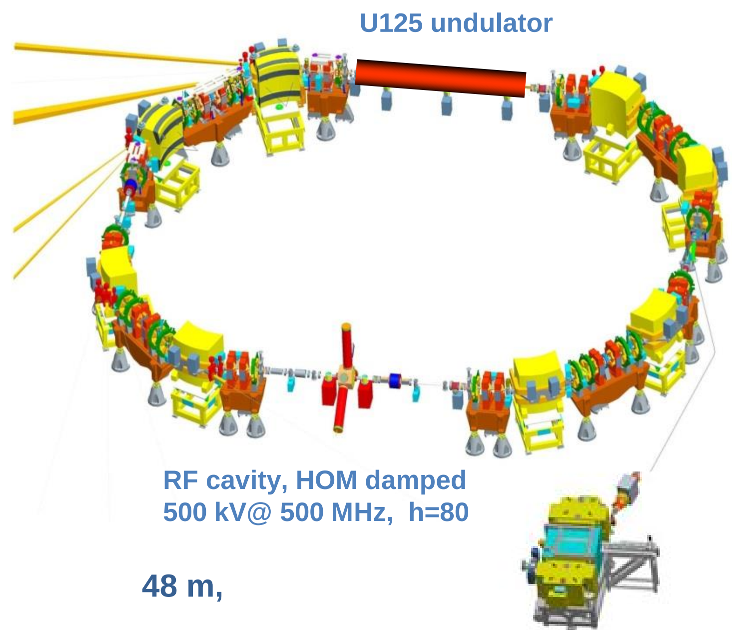
Ji Li on behalf of MLS machine team

Helmholtz Zentrum Berlin, Germany

OUTLINE

- The Metrology Light Source(MLS)
- Problems in operation
- Scientific development
- Upgrade plans

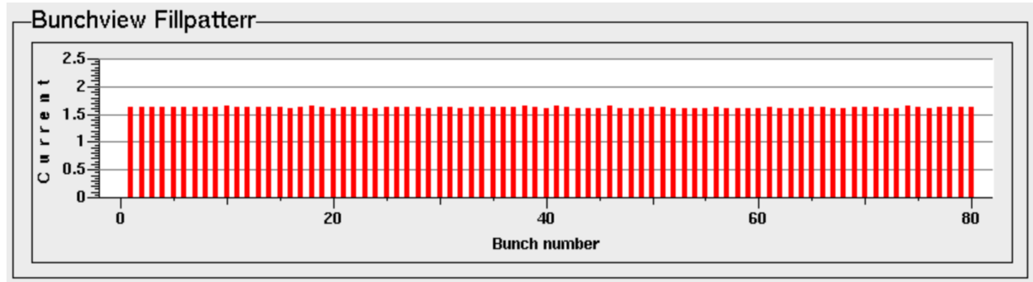
HZB / Dirk Laubner



Owned by PTB
Run by HZB

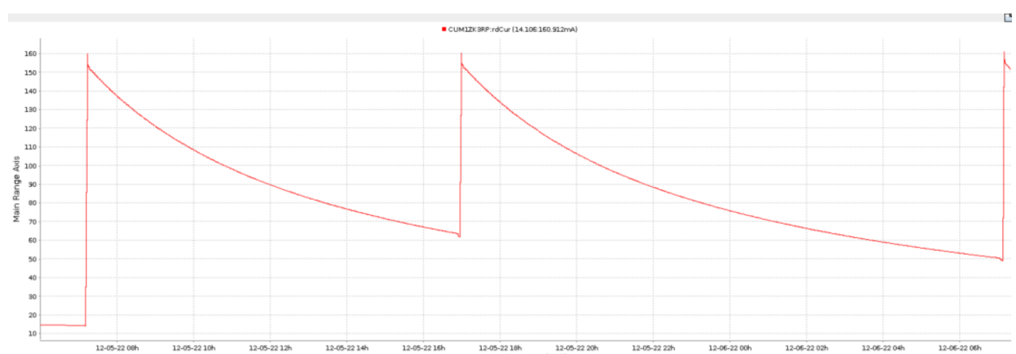
Circumference	**48 m,**
Revolution time	**160 ns = 1/6.25MHz**
Injection Energy	**105 MeV**
Operational Energy	**50 MeV to 630 MeV**
beam current	**1pA (1e-) – 200mA**
Momentum Comp. Factor	**-0.05 < α < 0.05**
Emittances at 630 MeV	**25 nmrad** (low emittance) **120 nmrad** (standard user) **250 nmrad**(low alpha)
Typical lifetimes in different operation modes	standard **6h @150mA, 100h@1pA** low emit. **2h @150mA** low Alpha **10h @150mA**

Homogeneous filling



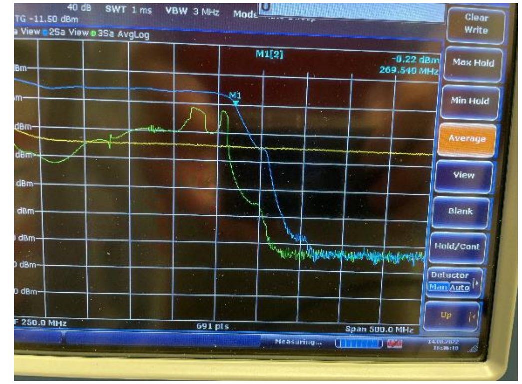
before 2020: 3 injections / d

after 2020: 2 injections / d



A broken amplifier of the BBFB system in August

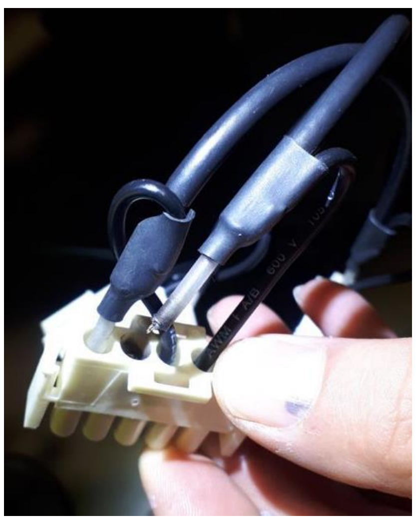
- Symptoms:
  - Beam loss in energy ramp due to instability
  - Optimizing parameters of BBFB solved the problem temporarily with unstable beam, but not reproducable
  - Output of horizontal amplifier abnormal
- Solutions:
  - Temporarily solved with a spare unit
  - replaced with new amplifiers in Nov. 2022



Courtesy of A. Schälicke

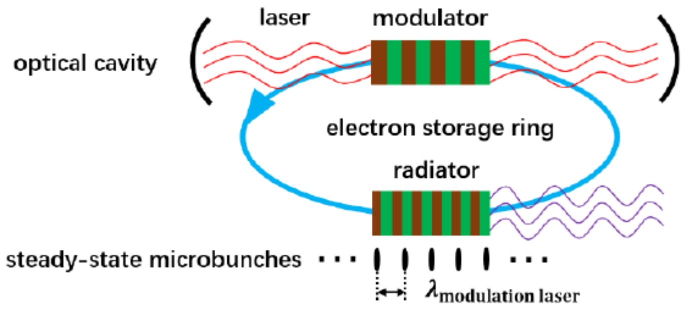
○ Microtron modulator failure in October

- broken cable in the controller
- broken capacitors found in IGBT units
- upgrade in consideration, in comunication with colleagues @ASTRID, Denmark

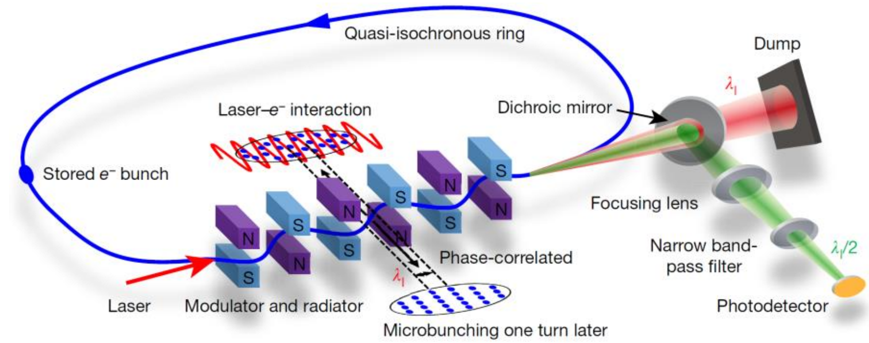


Courtesy of H. Glass, T. Atkinson. D. Schüler

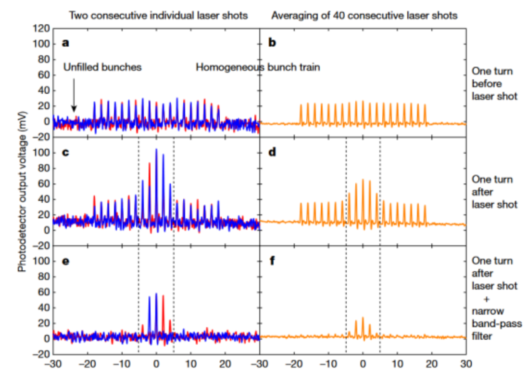
Successful SSMB PoP experiment @ the MLS

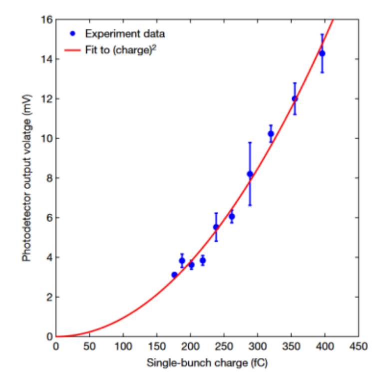


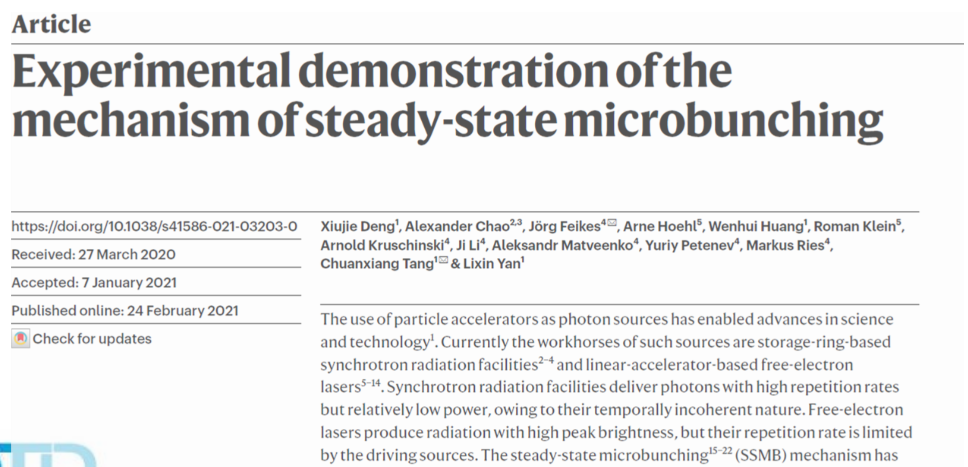
principle of Steady-State MicroBunching(SSMB)



- laser modulator to form optical buckets like RF buckets
- Microbunching for high power + steady state for high repetition rate
- Proposed by A. Chao and D. Ratner
- On-going collarbration: HZB, PTB (Berlin, Germany) and Tsinghua university, Beijing, China since 2017






Article

Experimental demonstration of the mechanism of steady-state microbunching

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Xiujie Deng[1], Alexander Chao[2,3], Jörg Feikes[4], Arne Hoehl[5], Wenhui Huang[1], Roman Klein[5], Arnold Kruschinski[4], Ji Li[4], Aleksandr Matveenko[4], Yuriy Petenev[4], Markus Ries[4], Chuanxiang Tang[1] & Lixin Yan[1]

The use of particle accelerators as photon sources has enabled advances in science and technology[1]. Currently the workhorses of such sources are storage-ring-based synchrotron radiation facilities[2–4] and linear-accelerator-based free-electron lasers[5–14]. Synchrotron radiation facilities deliver photons with high repetition rates but relatively low power, owing to their temporally incoherent nature. Free-electron lasers produce radiation with high peak brightness, but their repetition rate is limited by the driving sources. The steady-state microbunching[15–22] (SSMB) mechanism has

Deng, X., Chao, A., Feikes, J. *et al.* Experimental demonstration of the mechanism of steady-state microbunching. *Nature* **590,** 576–579 (2021)

Further experiments for SSMB

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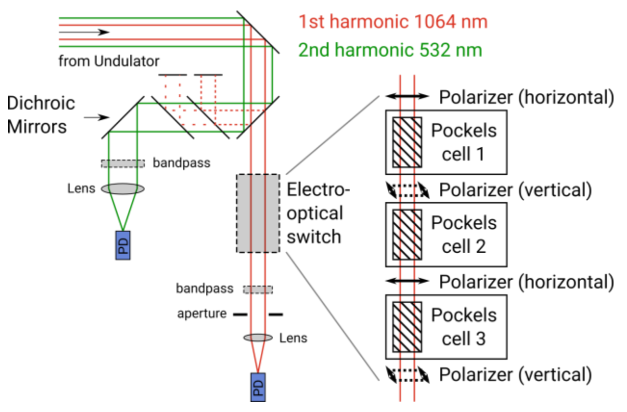
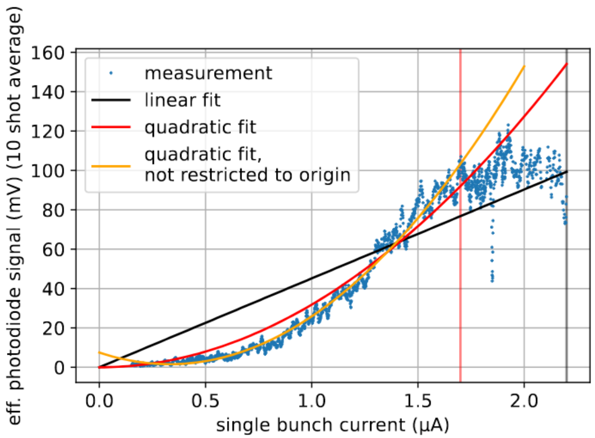
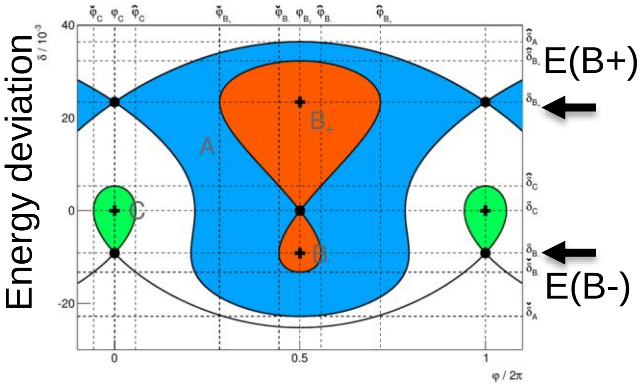


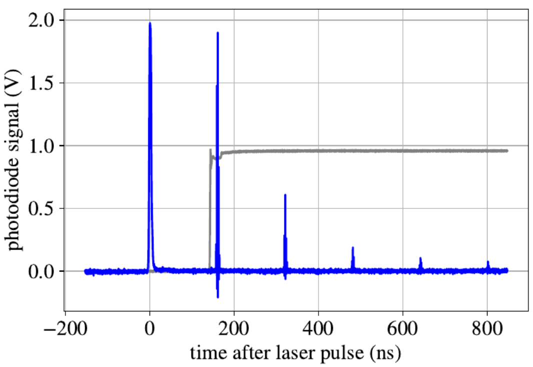


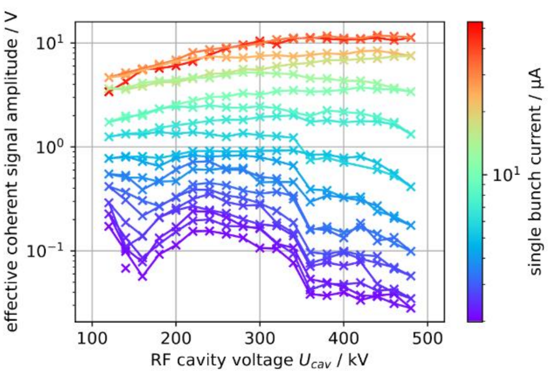
Investigations of longitudinal phase space: coherent signal only in a specific alpha bucket state. Why?

Coherent SSMB signal for multiple revolutions → Why?

Unexpected dependence of SSMB signal strength to RF cavity voltage:







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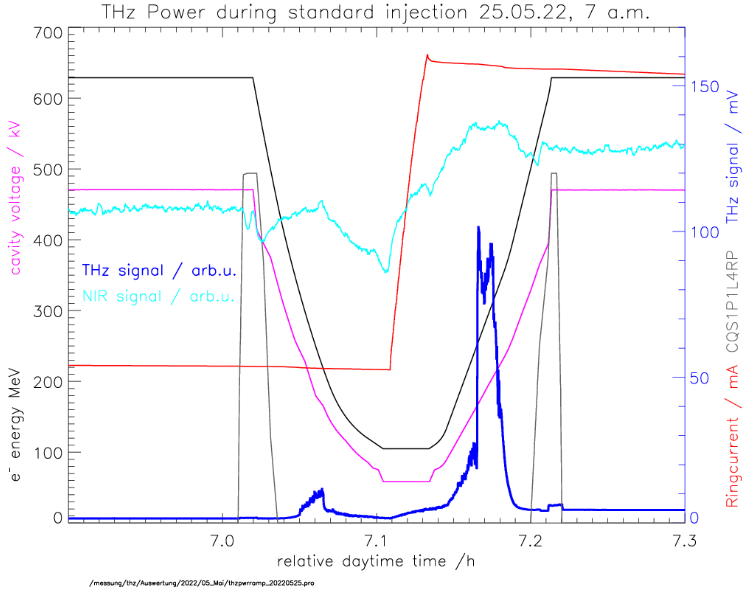
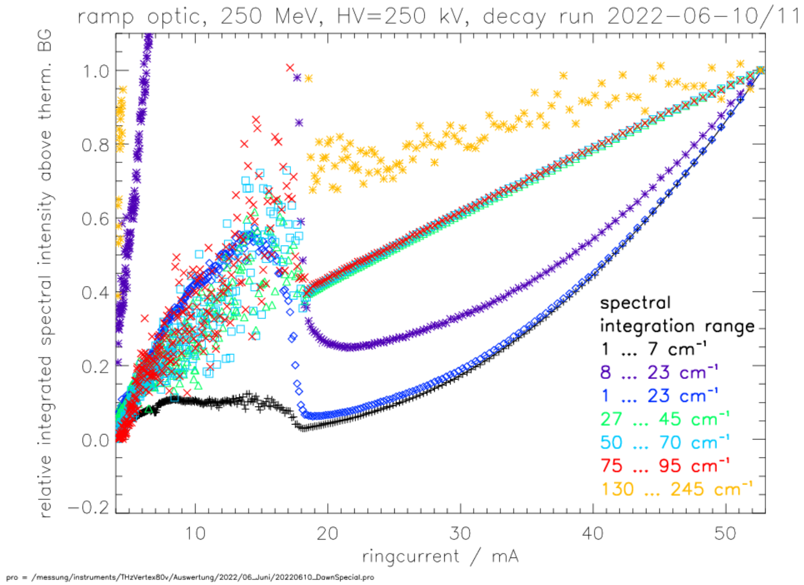
Courtesy of A. Kruschinski, M. Ries

coherent radiation @250 MeV energy ramp with large alpha





Courtesy of Arne Hoehl @ PTB

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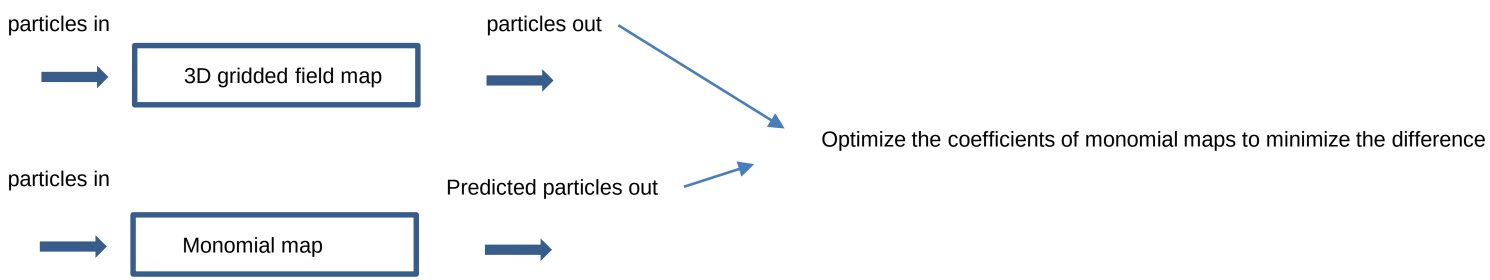
A classical approach when the analytical field representation is unknown:
Taylor map → Lie map -> factorization-> momonial maps -> explicit symplectic integration

$$\mathcal{M} = e^{:G_2:}e^{:G_3:}e^{:G_4:}e^{:G_5:}e^{:G_6:}e^{:G_7:}e^{:G_8:}e^{:G_9:}.$$

Our approach for studying the Robinson wiggler:



4D case: x, p_x, y, p_y

$$e^{:G_2:} = e^{a_{2000}:x^2:}e^{a_{1100}:xp_x:}e^{a_{0200}:p_x^2:}e^{a_{1010}:xy:}e^{a_{0110}:p_xy:} e^{a_{0020}:y^2:}e^{a_{1001}:xp_y:}e^{a_{0101}:p_xp_y:}e^{a_{0011}:yp_y:}e^{a_{0002}:p_y^2:}$$

⟺ Linear transfer matrix

fit the Jacobian matrix of second-order monomial maps to the Jacobian matrix of tracking results through the field map

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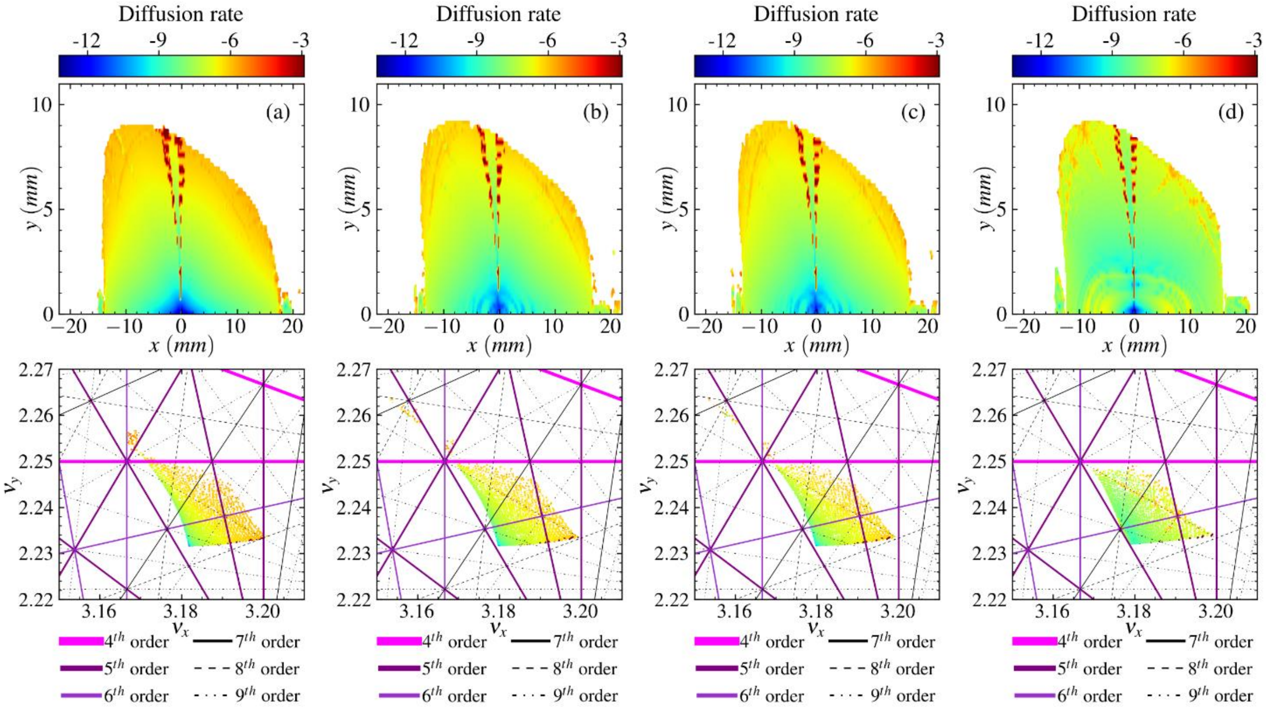
Comparison with other symplectic tracking methods which are based on analytical representation of the magnetic field in the Robinson wiggler



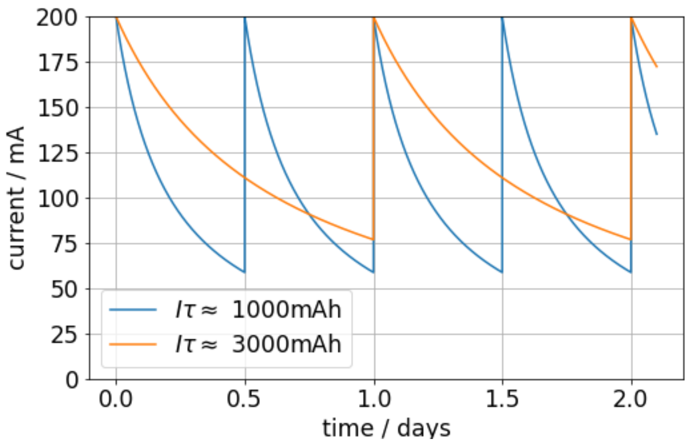
Dynamic aperture with diffusion rate based on

(a) implicit Runge-Kutta integrator (b) Wu-Forest-Robin integrator (c) analytical generating function method (d) monomial map

J. Li. *et al.* Sympletic tracking methods for insertion devices: a Robinson wiggler example, *arXiv preprint arXiv:2210.05345* (2022)

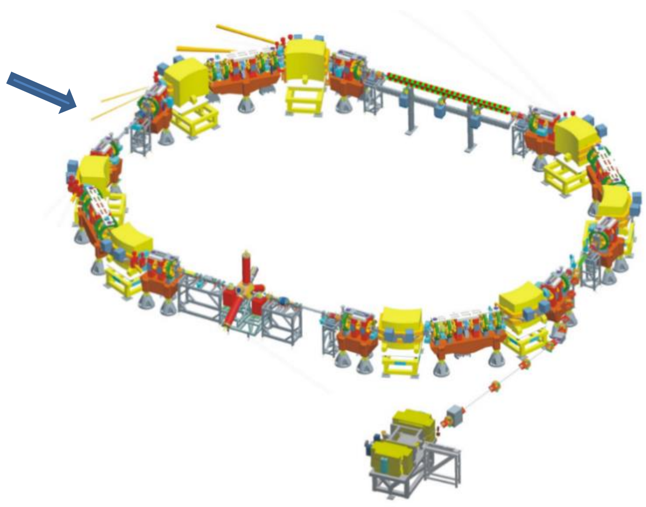
Upgrade plan: 1.5GHz active Landau cavity

- Collaboration: HZB, ALBA, DESY
- Successful experiments of a prototype at BESSY II
- To improve user operation with better lifetime
- high potential for low alpha and SSMB research
- Ingredient for MLS II



Courtesy of M. Ries

1.5 GHz Landau cavity



Other plans

- IOT→ Solid-state Amplifier in April. 2023 for 4 weeks (H. Stein, A. Heugel, B. Schriffer…)
- BPM system upgrade in 2023, turn-by-turn diagnose (G. Rehm…)
- A new EUV beamline for Zeiss in 2023 (PTB EUV group)
- Operation with lower energy 450 MeV to save energy→ still under discussion

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- 800 MeV, 6 straights, at least 2 ID beamlines, top up
- Critical photon energy: 500 eV (down to 3 eV with lower beam energy)
- Circumference not decided yet:
  - 60 m: DBA with 5 straights
  - 90 m: DBA or TBA
  - 120 m: QBA
- Operational modes:
  - Standard user: 200 mA or higher, trade off between lifetime and low emittance
  - SSMB/low alpha: short bunches, good control of higher order alpha
- Design approach: Robust design with optimized performance of nonlinear dynamics
- A dedicated postdoc position filled since September.2022

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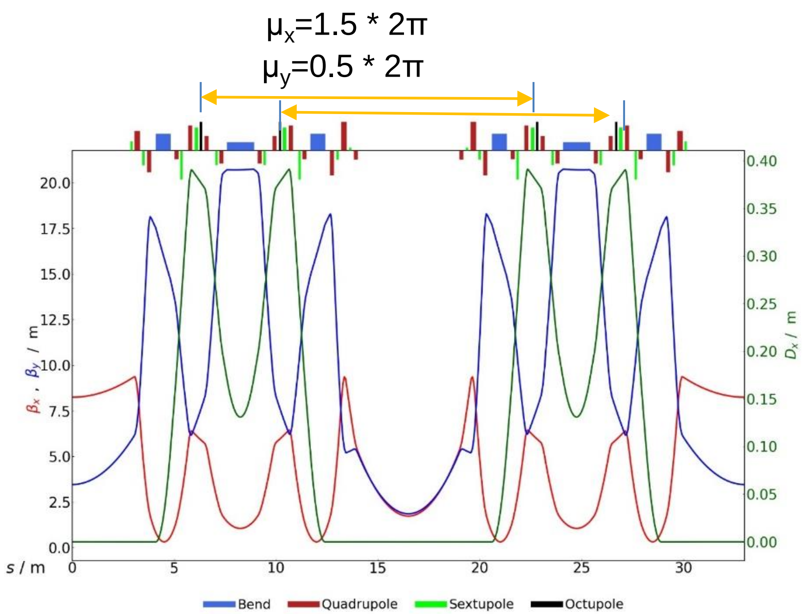
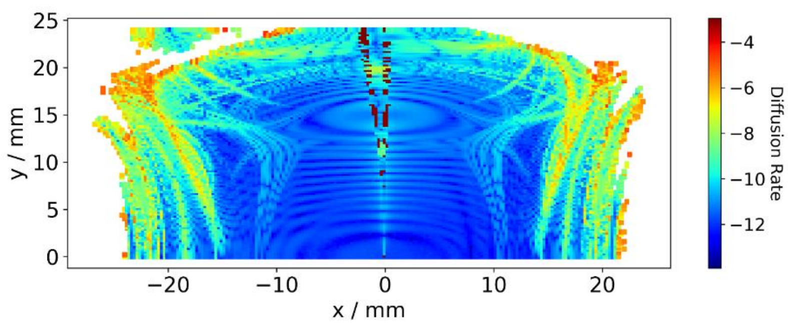
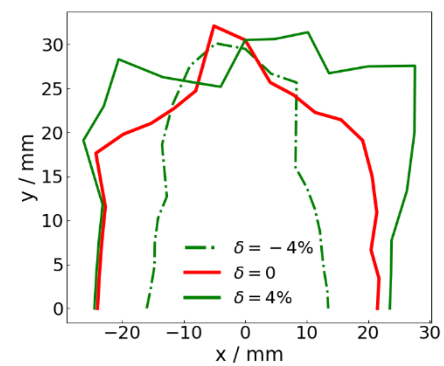


Parameters of the MLS II storage ring (draft)

Parameter	Value
Energy	1.2 GeV
Circumference	132 m
Harmonic number	220
Working point (H/V)	11.18 / 3.38
Natural chromaticities (H/V)	-19.83 / -16.48
Corrected chromaticities (H/V)	2 / 2
Radiation loss per turn	58.04 keV
Damping partition (H/V/L)	1.01 / 1.0 / 1.99
Damping time (H/V/L)	18.099 / 18.206 / 9.13
Natural emittance	7.54 nm
Natural energy spread	6×10^{-4}
Momentum compaction	3.21×10^{-3}
β_x, β_y @ high-β straight section center	8.25 / 3.47 m
β_x, β_y @ low-β straight section center	1.74 / 1.87 m

800 MeV now





Thanks for your attention!

Thanks to all the contributions from HZB and PTB staff !

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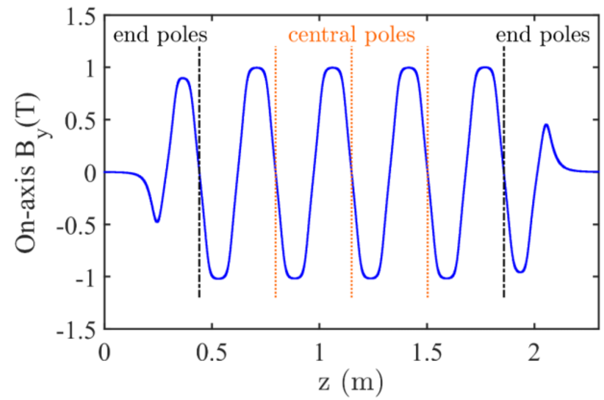
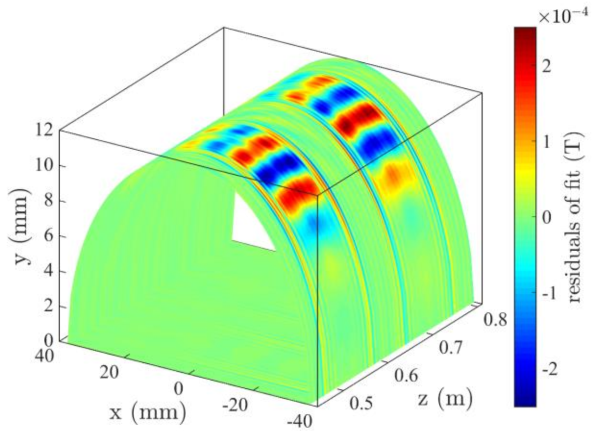
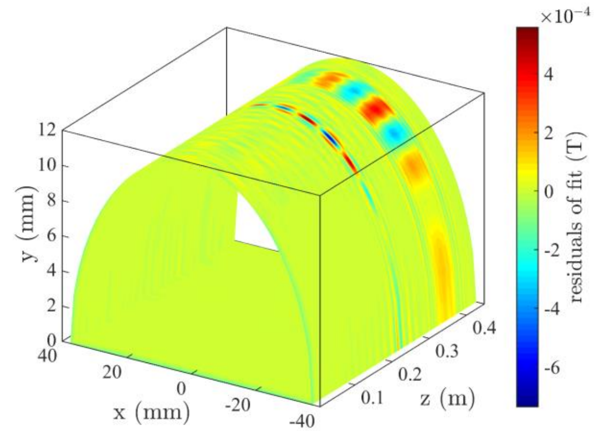
$$B_y = \sum_{m,n}^{M,N} C_{mn} cos(mk_x x + \theta_{mn}) cosh(k_{y,mn} y) \times sin(nk_z z + \phi_{mn})$$







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EXPLICIT SOLUTION OF MONOMIAL MAP(4D)

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$$e^{a:x^k p_x^l y^m p_y^n:} x = \begin{cases} x[1 + a(k-l)x^{k-1}p_x^{l-1}y^m p_y^n]^{l/(l-k)}, & \text{if } k \neq l \\ x e^{-akx^{k-1}p_x^{k-1}y^m p_y^n}, & \text{if } k = l \end{cases}$$

$$e^{a:x^k p_x^l y^m p_y^n:} p_x = \begin{cases} p_x[1 + a(k-l)x^{k-1}p_x^{l-1}y^m p_y^n]^{k/(k-l)}, & \text{if } k \neq l \\ p_x e^{akx^{k-1}p_x^{k-1}y^m p_y^n}, & \text{if } k = l \end{cases}$$

$$e^{a:x^k p_x^l y^m p_y^n:} y = \begin{cases} y[1 + a(m-n)y^{m-1}p_y^{n-1}x^k p_x^l]^{n/(n-m)}, & \text{if } m \neq n \\ y e^{-amy^{m-1}p_y^{m-1}x^k p_x^l}, & \text{if } m = n \end{cases}$$

$$e^{a:x^k p_x^l y^m p_y^n:} p_y = \begin{cases} p_y[1 + a(m-n)y^{m-1}p_y^{n-1}x^k p_x^l]^{m/(m-n)}, & \text{if } m \neq n \\ p_y e^{amy^{m-1}p_y^{m-1}x^k p_x^l}, & \text{if } m = n \end{cases}$$

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