

Metrology Light Source

Status, Upgrade and SSMB activities

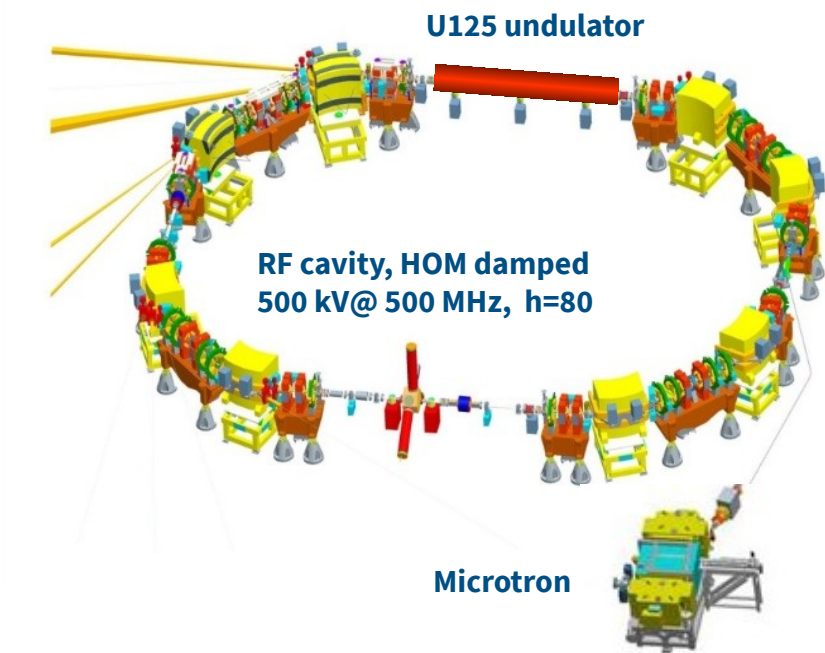
Carsten Mai on behalf of the MLS team

30 October 2025

A red circular badge with white text, positioned in the bottom right corner of the slide.

ESLS
2025
SOLEIL

THE METROLOGY LIGHT SOURCE



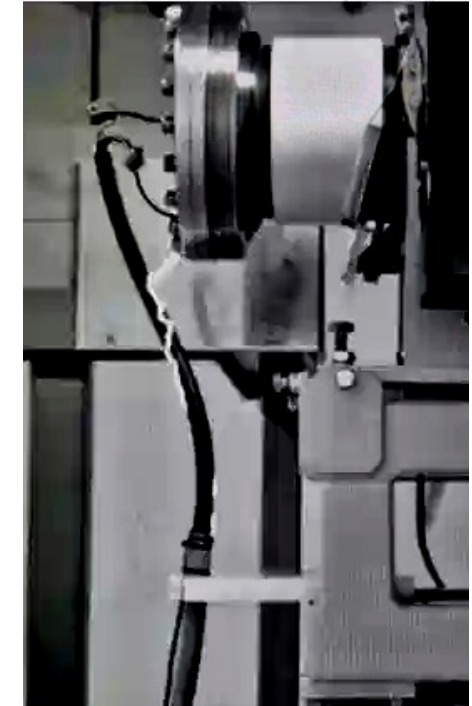
- Owned by Physikalisch-Technische Bundesanstalt (PTB)
- Operated and maintained by HZB
- First storage ring optimized for low alpha operation (short bunch operation → coherent THz emission)



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 Compaction Factor	-0.05 < α < 0.05
Emittances at 630 MeV	120 nm*rad (standard user) 25 nm*rad (low emittance) 250 nm*rad (low alpha)
Typical lifetimes in frequently used operation modes	standard user 6h @ 150 mA, 350 h @ 10µA low emittance 2h @ 150 mA low alpha 10h @ 150 mA

MLS OPERATION STATUS

- in general: very reliable machine operation with few interruptions
- interruptions mostly caused by: RF, Microtron
- damaged HV connector slightly reduced injection rate
- multiple power outages
- outage of 1 (redundant) main cooler without effect on user operation
- 2-week shutdown in July
 - improvements for steady-state microbunching setup
 - integration of new laser
- specially EUV reflectometry under very high demand at PTB



POWER OUTAGES

- 3 power outages
 1. buffered, but outage too long
 - damage of 2 BPM electronics
 2. scheduled outage for UPS maintenance
 - again damage of BPM electronics
 3. attack on power distribution system of neighboring city districts
 - attack:
 - fire at overhead-to-underground transition of HV cables
 - September 9, 05:09 → September 11, 16:33
 - meanwhile 50000 people without electricity
 - letter of confession was published
 - attack aimed at indirectly warfare-related industry & research
- under investigation

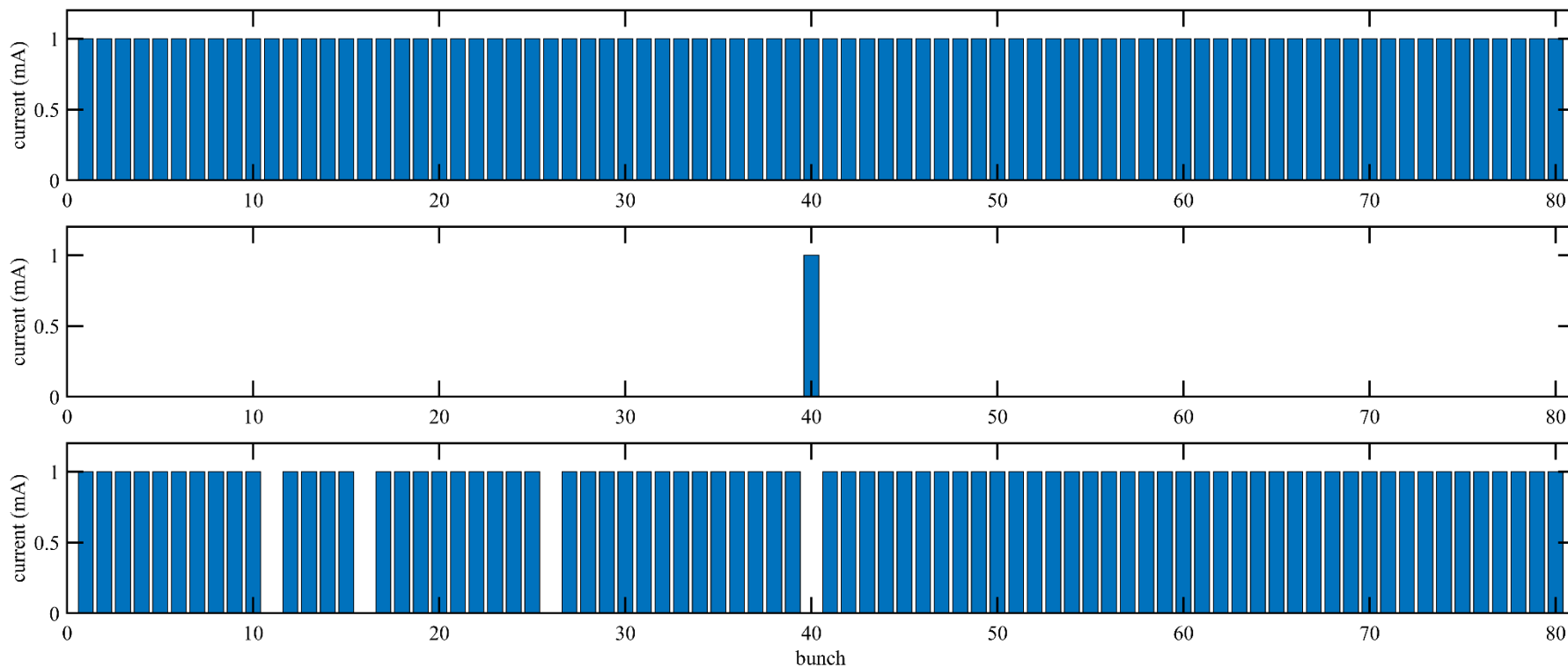


SINGLE BUNCH OPERATION

- special user request: single bunch operation
- machine not optimized for single bunch
 - vacuum conditions
 - single bunch → single user

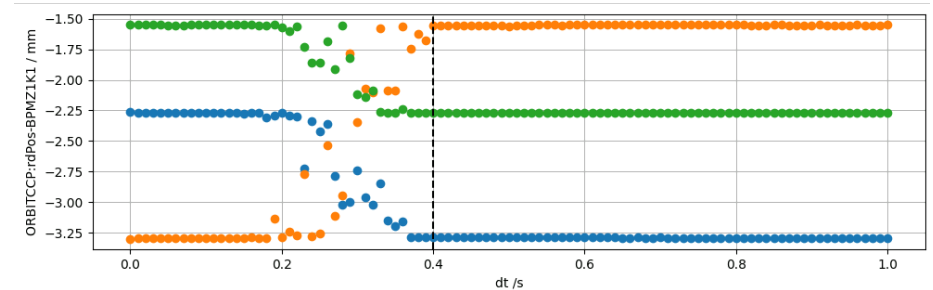
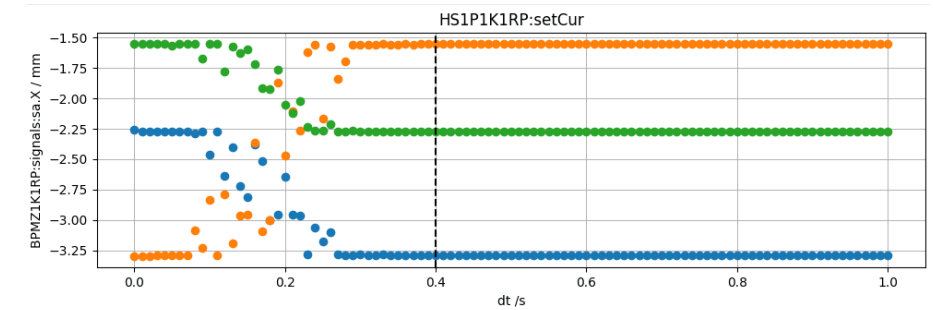
solution:

- “inverse” single bunch
- bunch-cleaning of $h/2$, $h/3$, $h/5$, $h/7$
- deconvolution of detector response under test and fill pattern



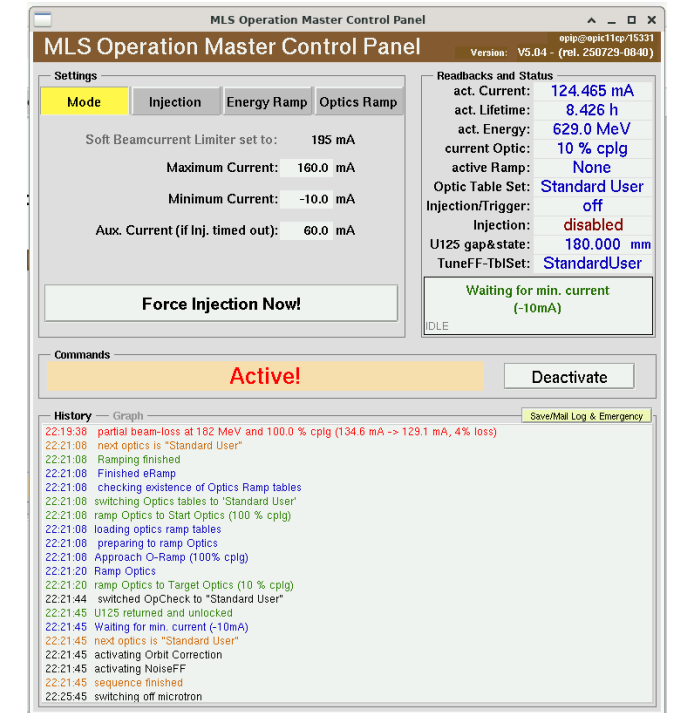
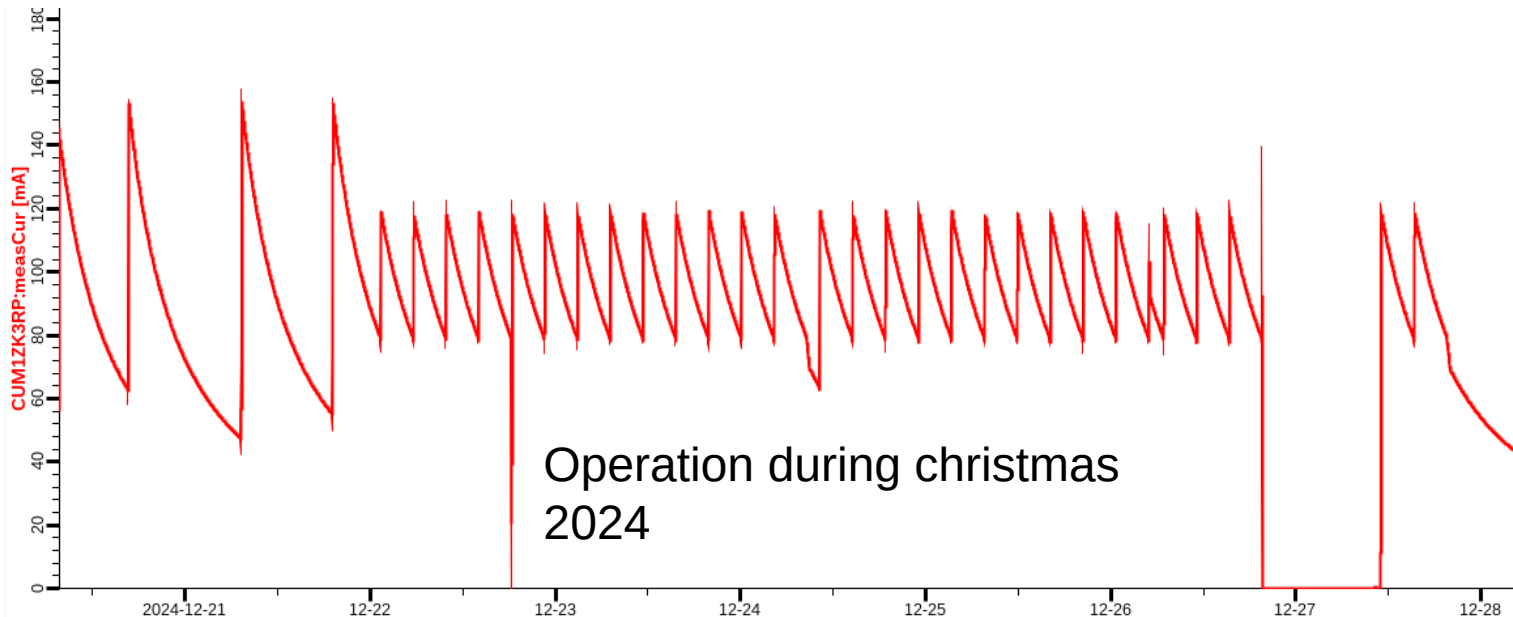
TURN-BY-TURN ORBIT DATA

- commissioning of Libera Spark BPM electronics started in 2024
- stable operation
- improvement of readout speed:
0.5 Hz \rightarrow 10 Hz for slow acquisition + 6.25 MHz
- speed of beam-based alignment improved (~ 8 minutes / BPM)
- speed test / reaction test of all main power supplies
- backwards-compatibility of orbit-feedback code
- rewiring of BPM polarity in shutdown



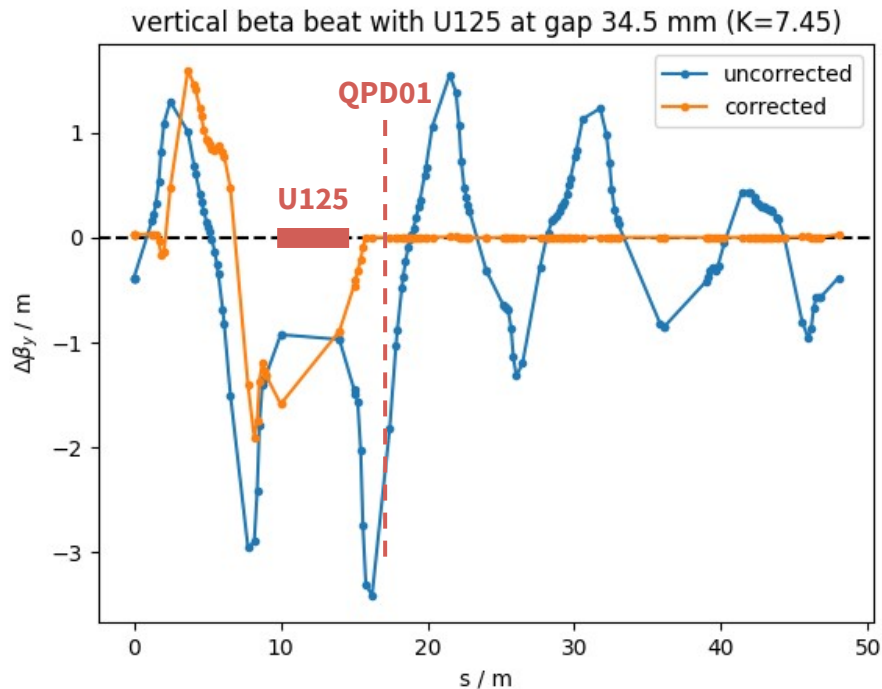
AUTOMATIC ENERGY RAMP OPTIMIZATION

- ramped operation: injection at 105 MeV → 629 MeV
- operation is based on “master” program relying on ramp tables
- any unwanted setup change will be gone after next injection
- very steady operation with little necessity of expert knowledge during shift
- tune optimization needed at interval of 3-4 weeks

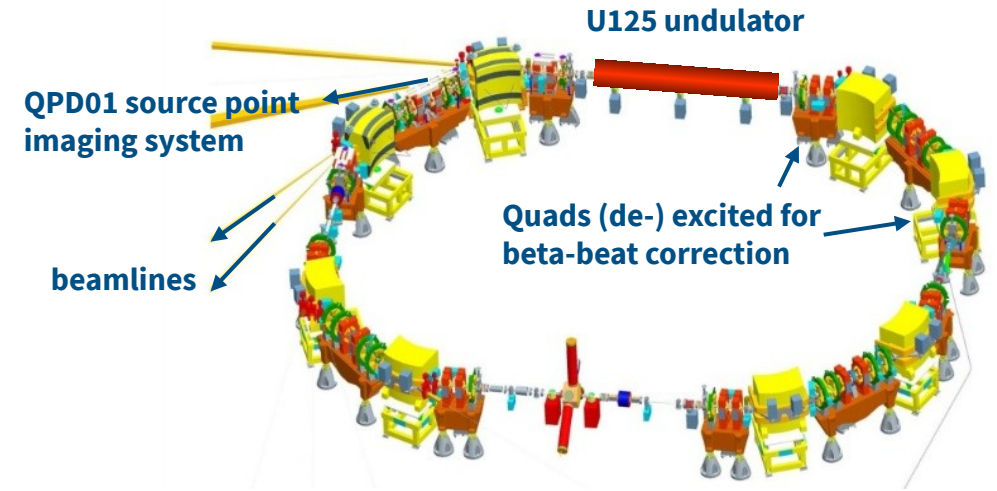
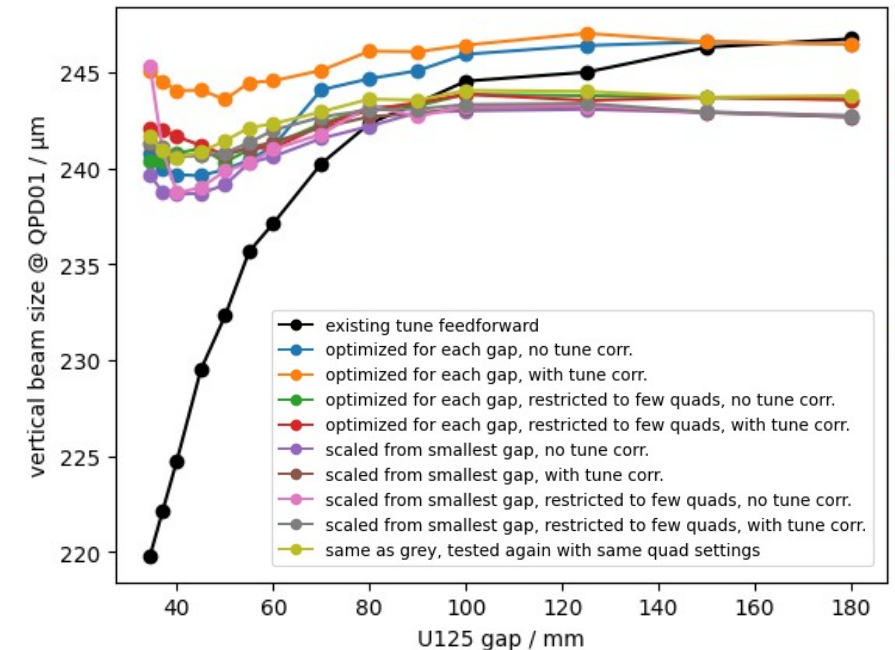


BETA-BEAT CORRECTION FOR U125

- At small gaps (wiggler mode), U125 introduces strong vertical focusing leading to beta-beat
- So far only symmetric quadrupole-feedforward to maintain tunes
- Establish beta-beat correction using quads in front of U125 (simulation with elegant WIGGLER element, then tune correction on real machine)

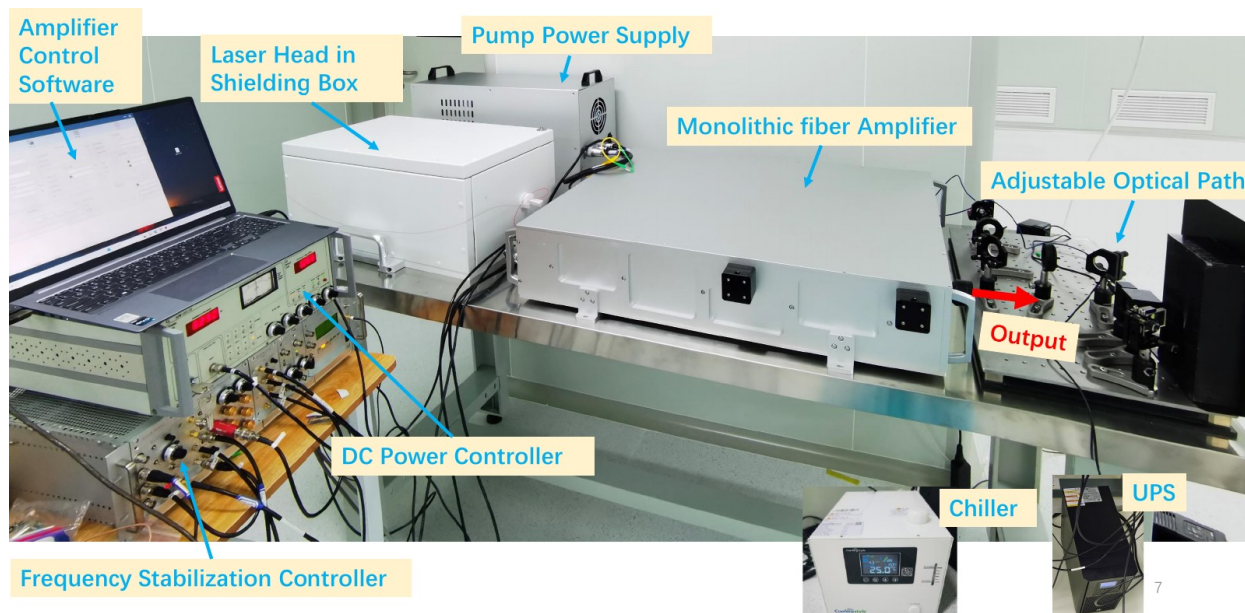
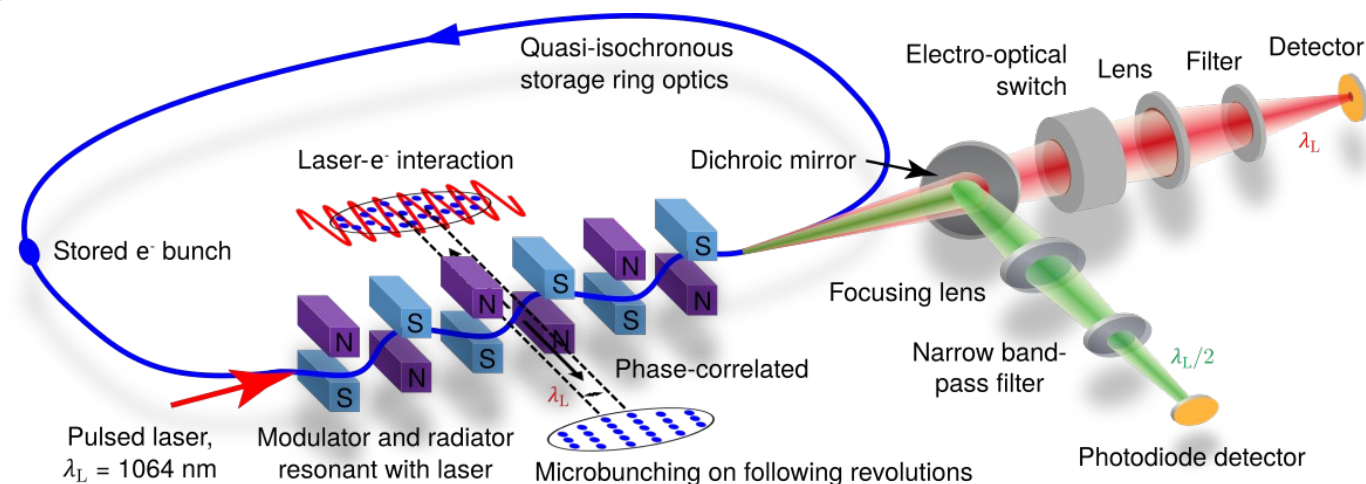


Results for vertical beam size at QPD01:
(Different variations of beta-beat correction in color, original tune-feedforward in black)



PREPARING PHASE II OF THE SSMB POP EXPERIMENT

- Phase I experiments concluded in 2024
- Goal of phase II: Show persistent microbunching over 1000 revolutions with synchrotron oscillations in microbuckets
- New laser for turn-by turn modulation is installed in MLS bunker, first experiments planned November 2025



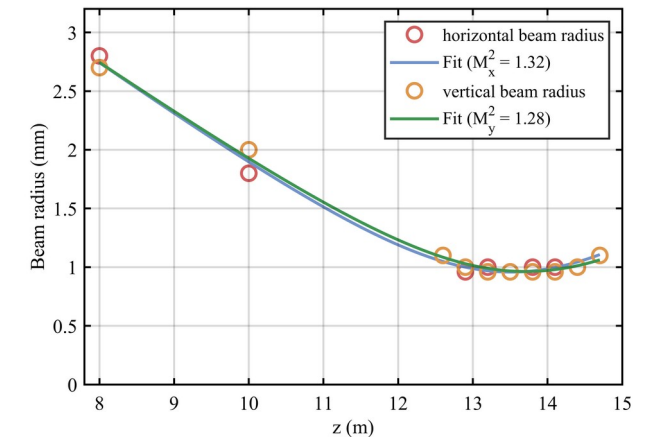
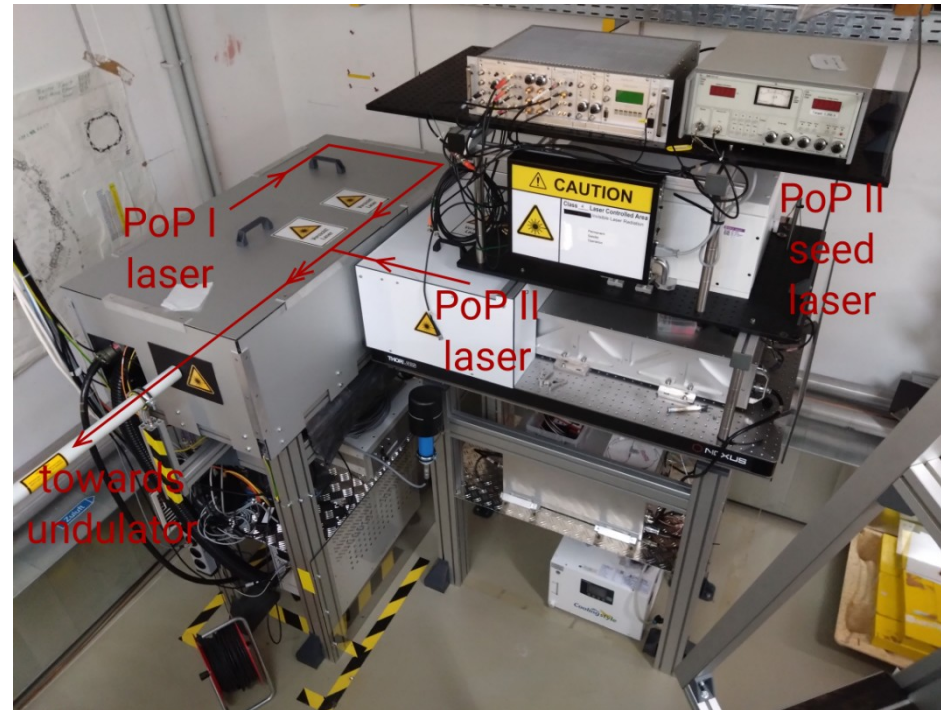
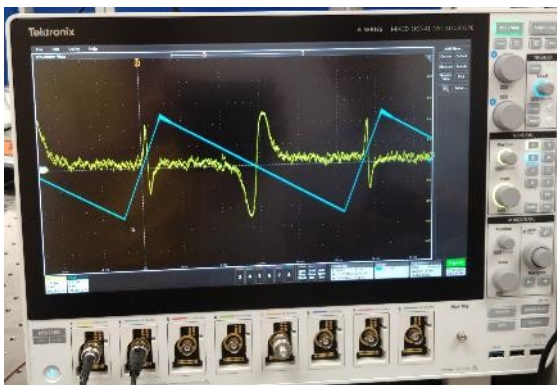
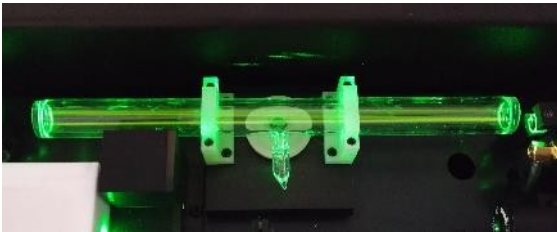
	Phase I laser	Phase II laser
Wavelength	1064 nm	1064 nm
Pulse length	5 ns FWHM	0.5 ns FWHM
Peak power	~ 20 MW	~ 20 kW
Repetition rate	1.25 Hz	6.25 MHz

X. Deng et al., Nature **590**, 576–579 (2021).

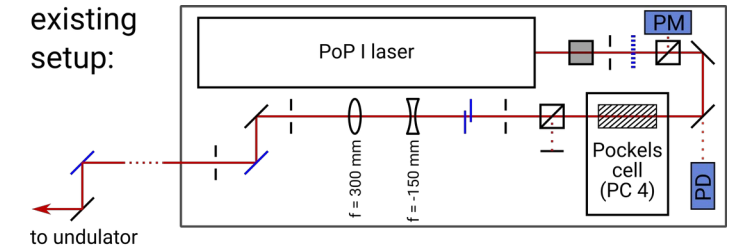
A. Kruschinski et al., Communications Physics **7**, 160 (2024)

COMMISSIONING AND INTEGRATION OF POP II LASER

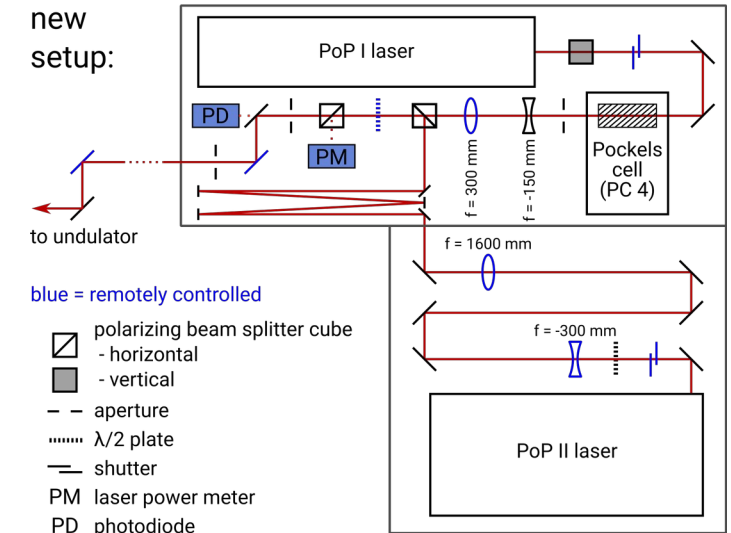
- Commissioning in laser lab at MLS: test laser performance and frequency-locking of seed laser, design and test telescope
- Laser setup in the bunker: Install PoP II laser in parallel to existing PoP I laser, facilitating operation of both systems



existing setup:

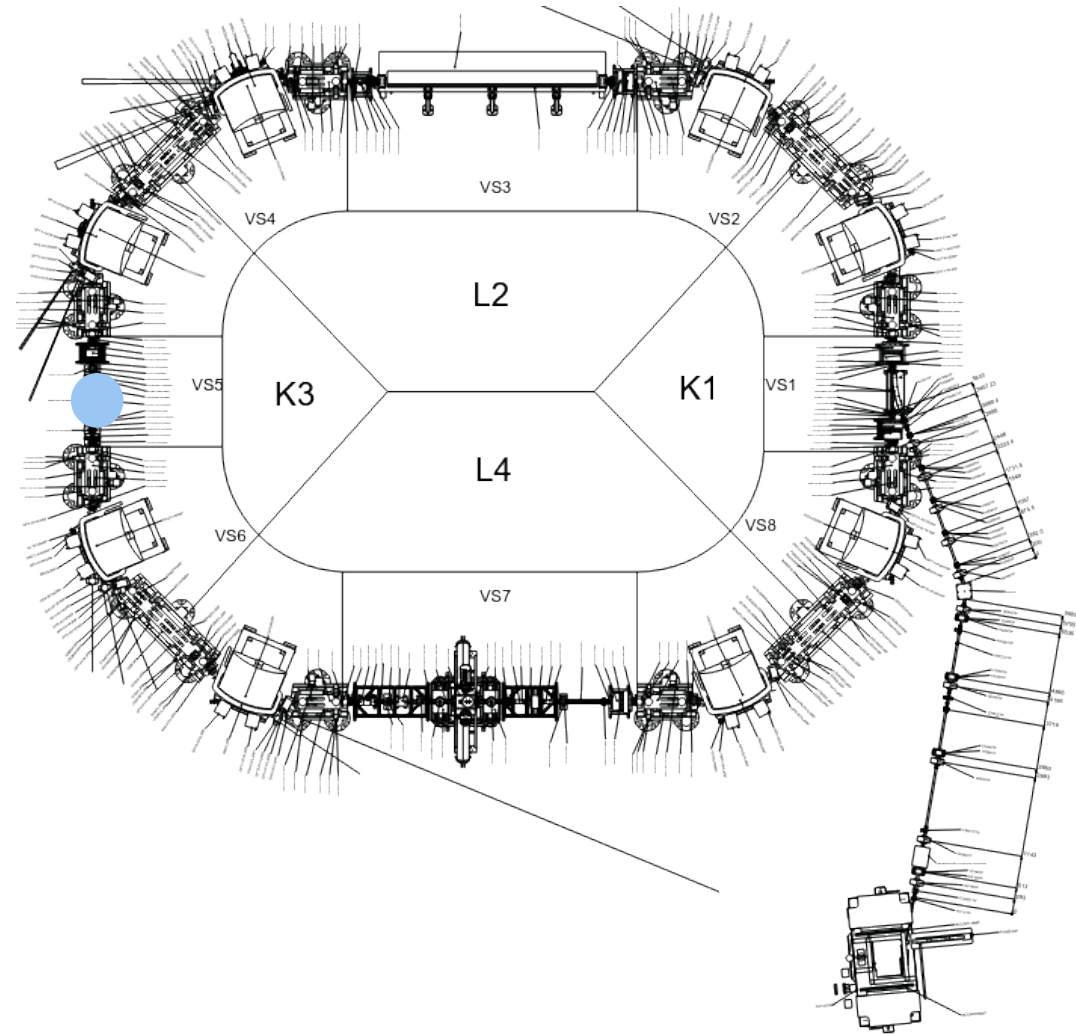
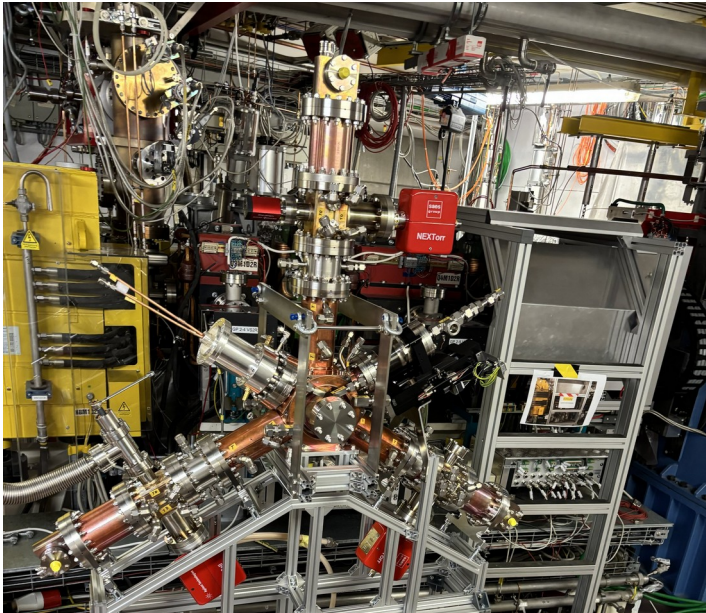


new setup:



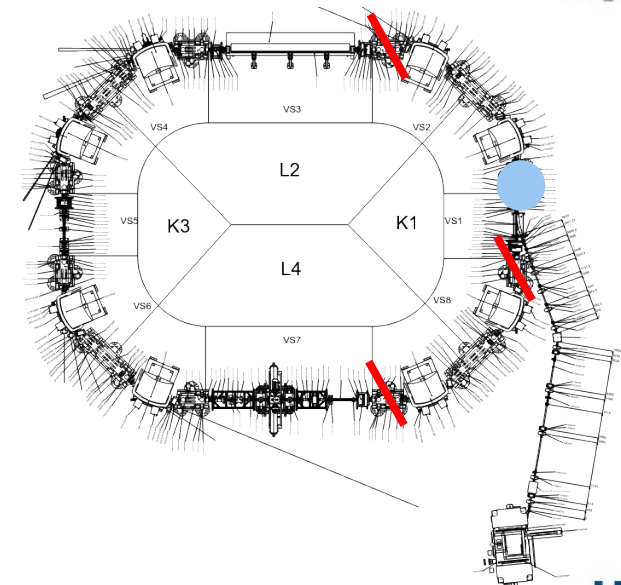
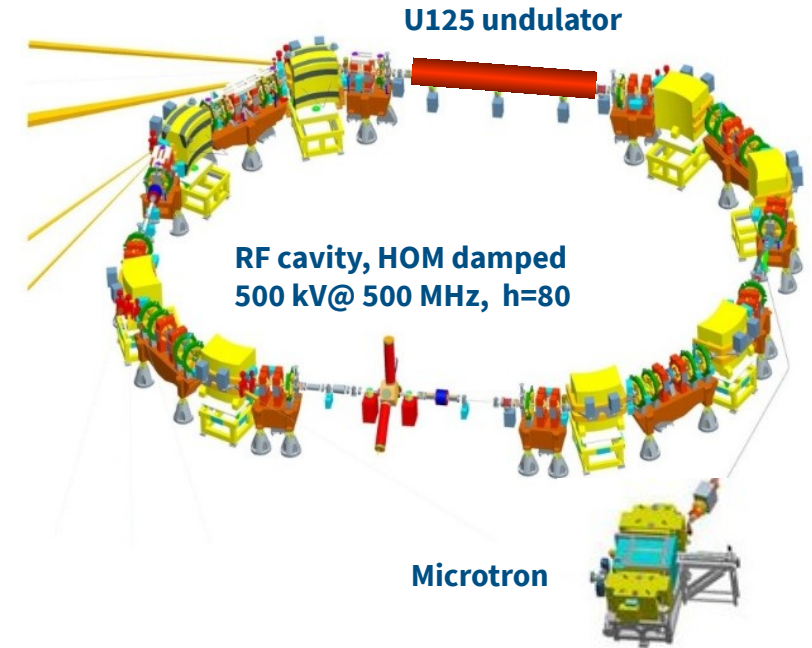
HARMONIC CAVITY

- 1.5 GHz Cavity delivered
- waveguide installed
- LLRF system (Dimtel) delivered
- installation:
 - short shutdown in January 2027



MLS+

- study for machine “**MLS2**” completed
 - 800 MeV, green-field
 - full-energy injector linac
 - keeping an upgraded MLS alive is preferred, instead
- instead focus on
 - keeping high availability and reliability
 - installation of 2nd undulator and replacement of U125
 - injection: non-linear kicker instead of 4-kicker bump
 - magnet renovation
 - extend building to house additional beamlines
- status of MLS+
 - agreement between PTB and HZB expected to be reached in Nov 2025
 - 2-year phase for CDR development
 - 3-year phase for TDR development





SUMMARY

- operation very stable
- great improvement: new BPM electronics!
- SSMB
 - successful completion of phase I
 - 2-year project, phase II: increased repetition rate
 - energy modulation possible with reduced peak power
 - next week: joint measurements with colleagues from Tsinghua University
- MLS+
 - work on design reports will start in 2026