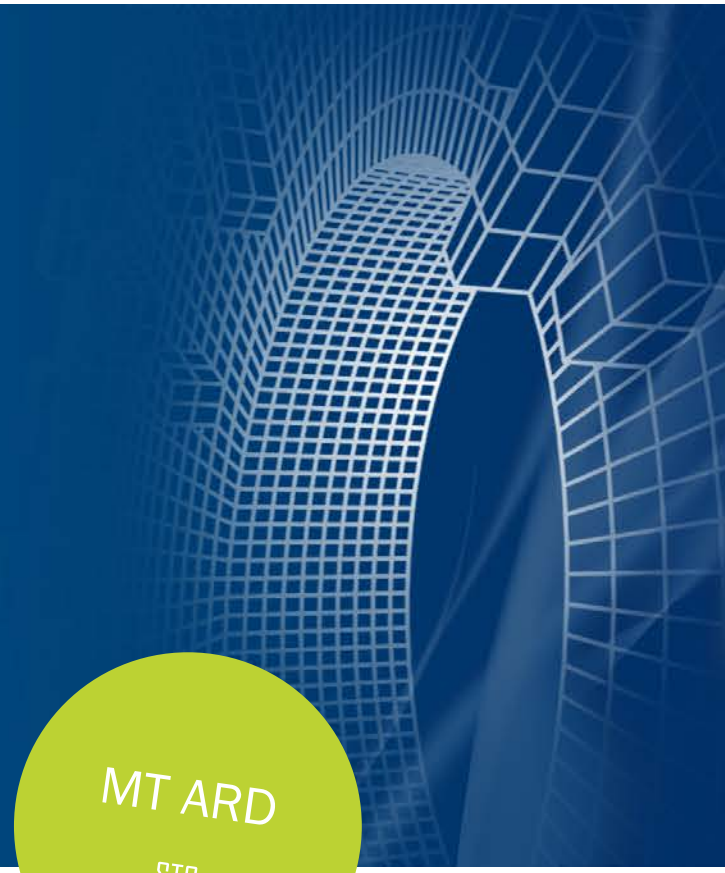
HZB BESSY II Light Source

HZB ACCELERATOR FACILITIES

operation, development, research



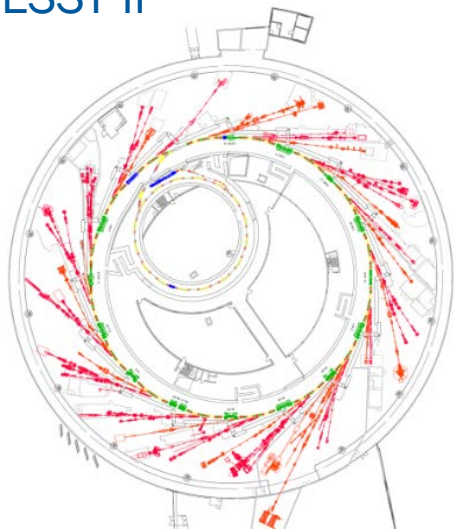
07.09.2022, Markus Ries et al.

MT ARD

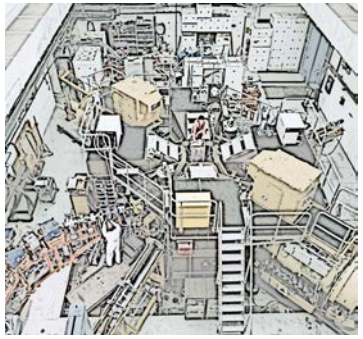
ST3

HZB / Dirk Laubner

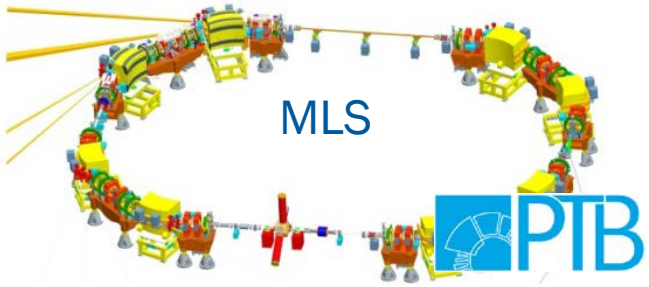
BESSY II



Cyclotron & Proton Therapy (eye tumours)



MLS



HZB Helmholtz Zentrum Berlin

BESSY III & MLS2

PTB

MT ARD | MT DMA

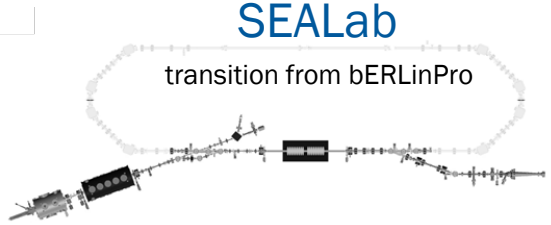
Advanced CW SRF
New Concepts and Prototypes
Advanced Beam Control, Diagnostics, Dynamics

ATHENA, InnoVEA, ACCLAIM

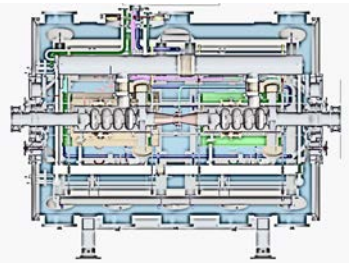
FLASH therapy, radiation hardness in MML

SEALab

transition from bERLinPro



VSR DEMO



LEAPS League of European Accelerator-based Photon Sources

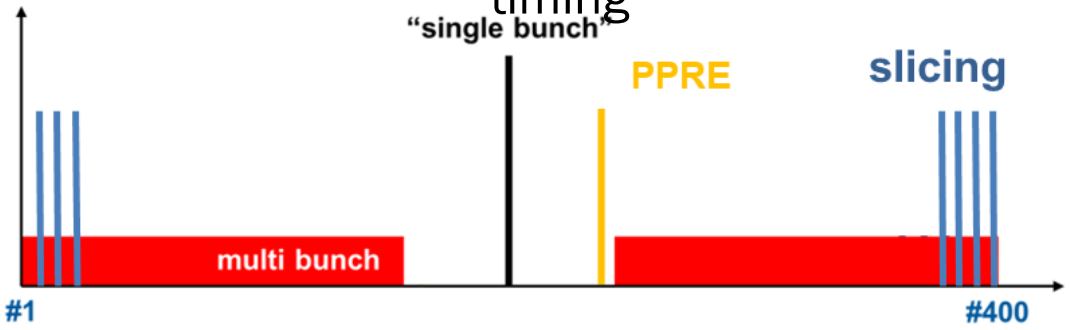
Digital LEAPS – ML, AI, Data
PerMaLic – permanent magnets
HarmonLIP – higher harmonic cavities

SupraLab@HZB

HZB BESSY II Light Source

BESSY II

hybrid filling pattern operation → flux, brightness, timing

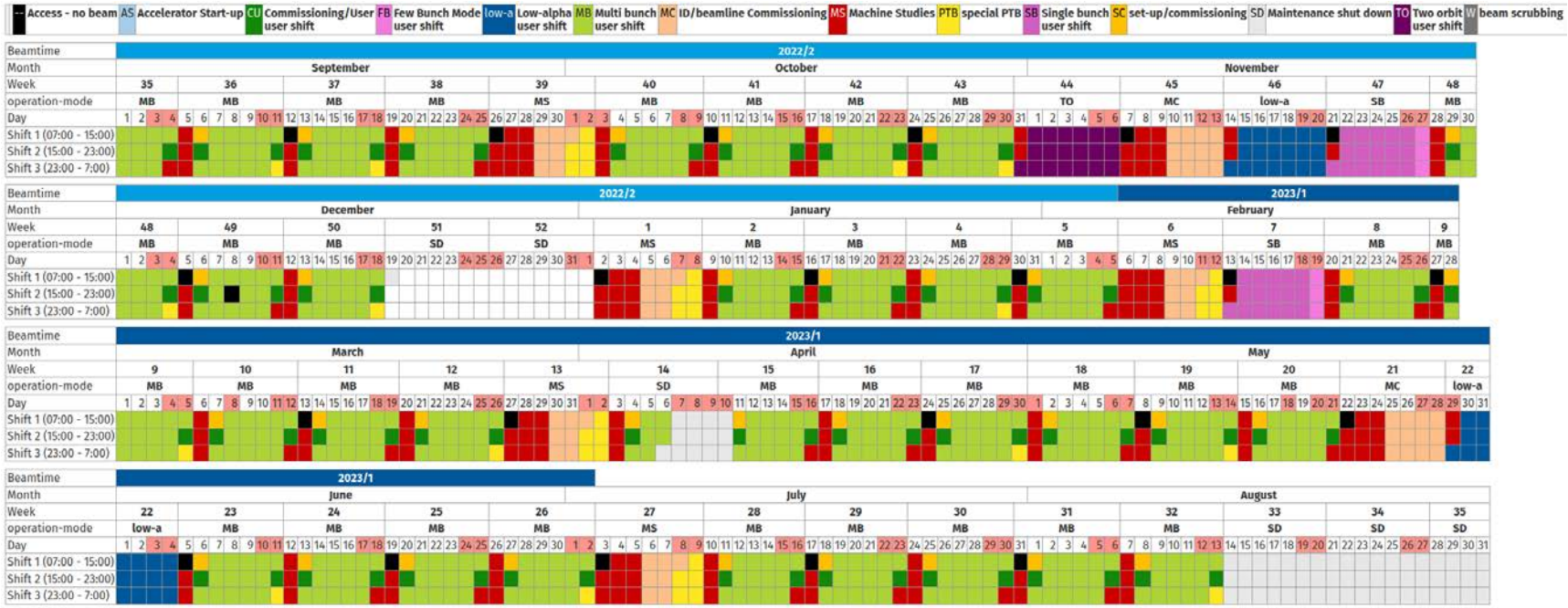


single bunch, few bunch → timing 100ps

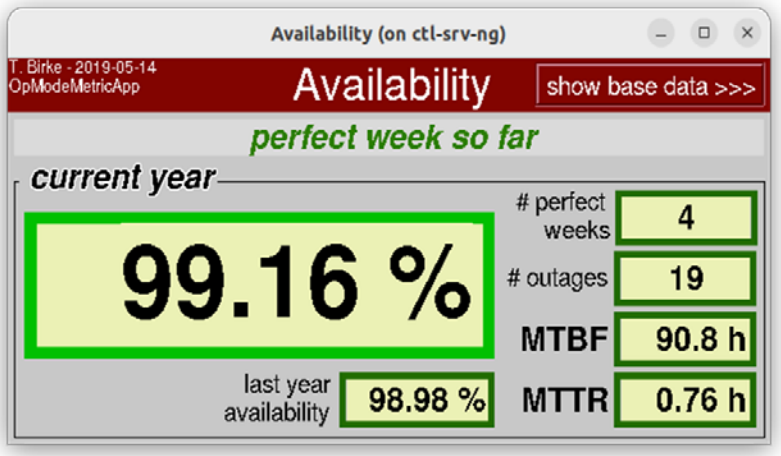
low-Alpha → timing 2ps, coherent THz radiation

- 1988 design, 1994 ground breaking, 1998 user operation
- 1.7 GeV, 300 mA
- decay machine with TopUp upgrade
- slicing facility upgrade
- superconducting wave length shifter (x2)
- in-vacuum undulator

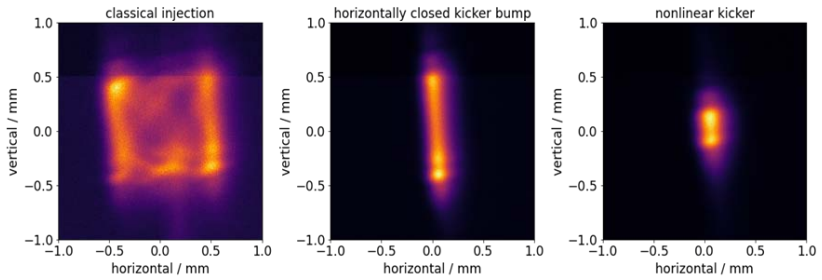
- 24/7 user operation
- multi user facility
- high availability
- special operation modes
- 47 weeks accelerator uptime in the next 12 months
- special boundary conditions for ARD @ user facility, e.g. TRIBs, 3HC…

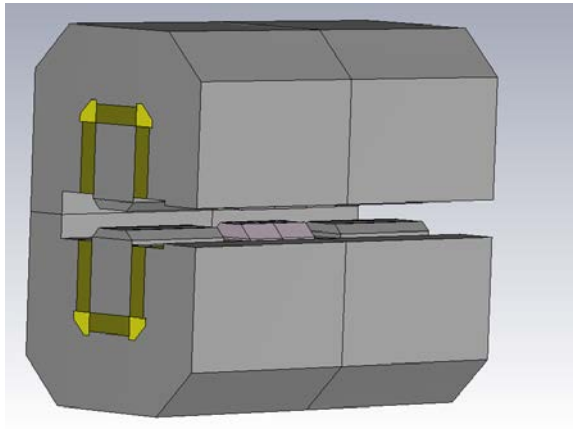


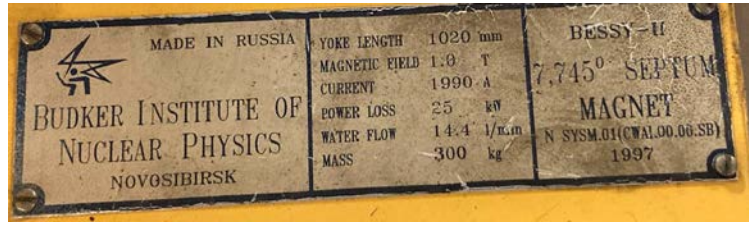
Year	Scheduled	Availability	Outages	MTBF	MTTR
2013	4505 h	96.5 %	105	42.9 h	1.5 h
2014	5408 h	92.9%	136	39.8 h	2.8 h
2015	3896 h	97.6 %	90	43.3 h	1.0 h
2016	4855 h	98.7 %	69	70.4 h	0.9 h
2017	4299 h	94.2 %	62	69.3 h	4.0 h
2018	3578 h	99.2 %	51	70.2 h	0.6 h
2019	4058 h	98.3 %	67	60.6 h	1.0 h
2020	3455 h	98.5 %	49	70.5 h	1.0 h
2021	4968 h	99.0 %	60	82.8 h	0.9 h

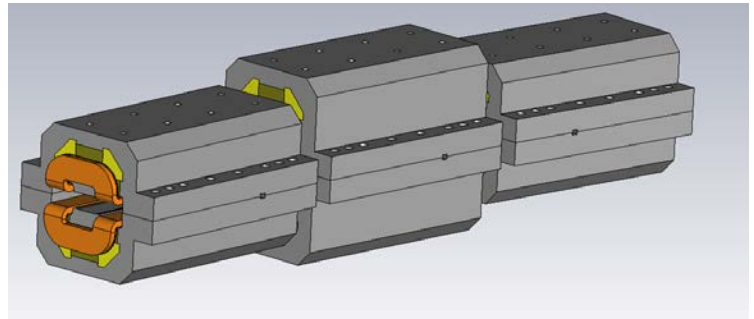


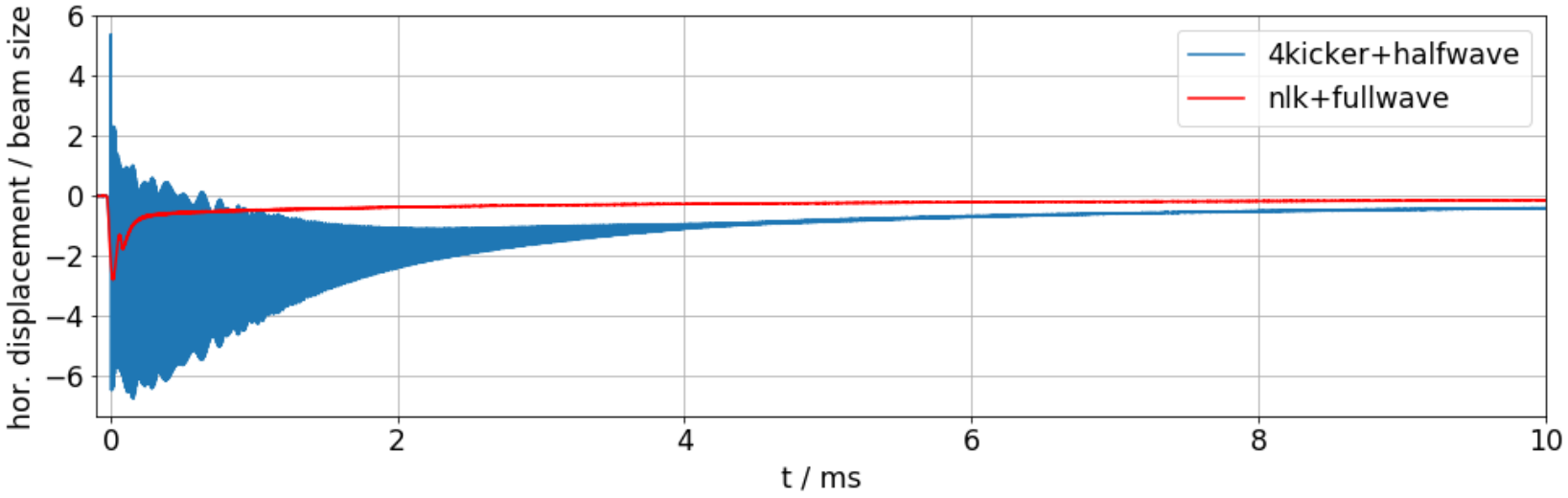
- BESSY II needs to perform at least until 2035
- focus on reliability, stability, sustainability
- ARD towards BESSY III and MLSII



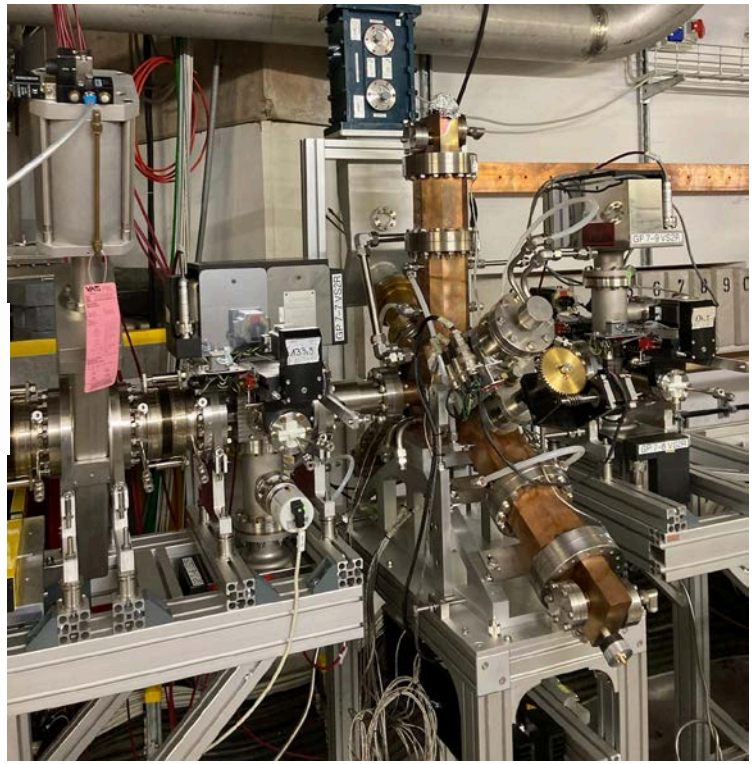


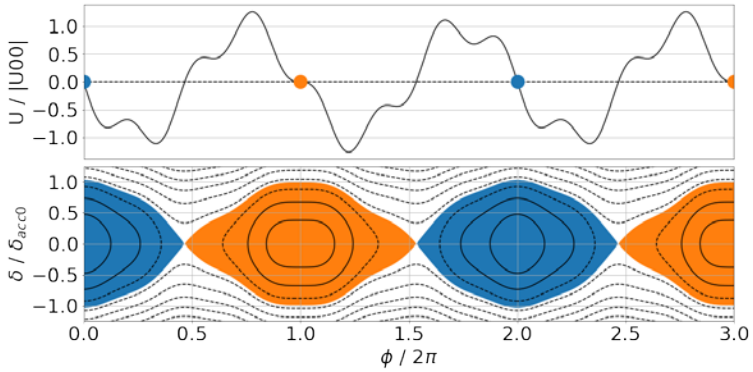


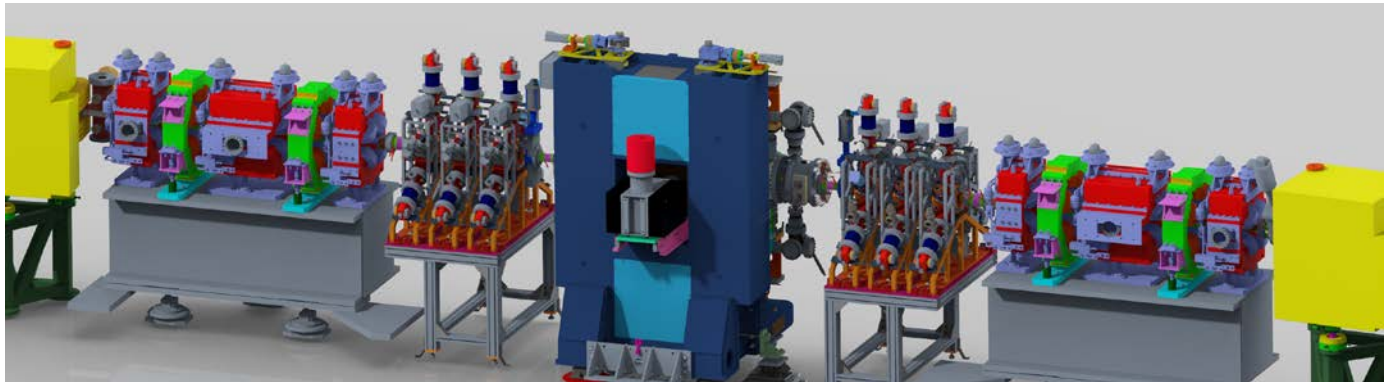




- collaboration on prototype project with ALBA and DESY
- ideal test environment at HZB
- first NC, active, HOM-damped harmonic cavity in a storage ring – commissioning runni these weeks
- essential ingredient for BESSY III
- ARD on 1.75 GHz design (3.5th harmonic)



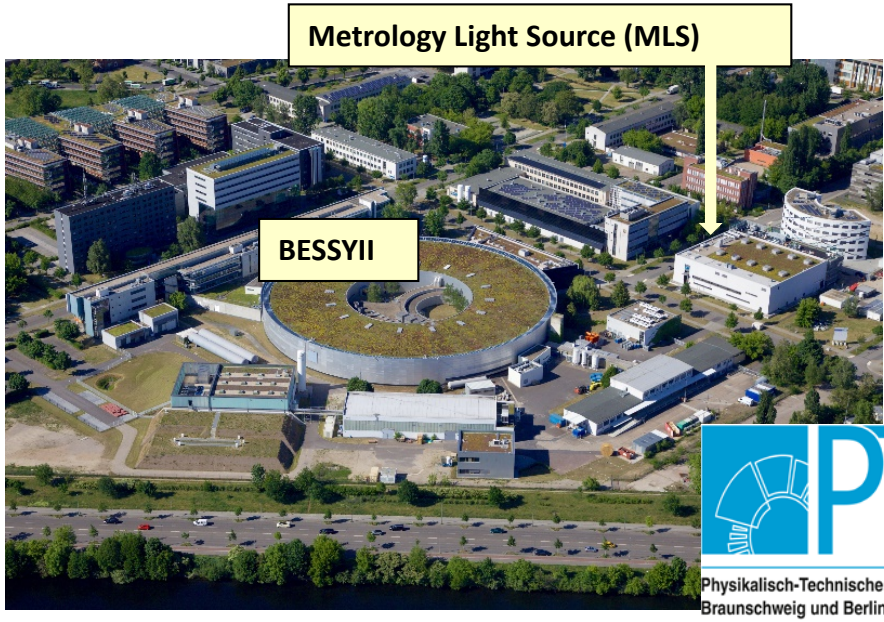


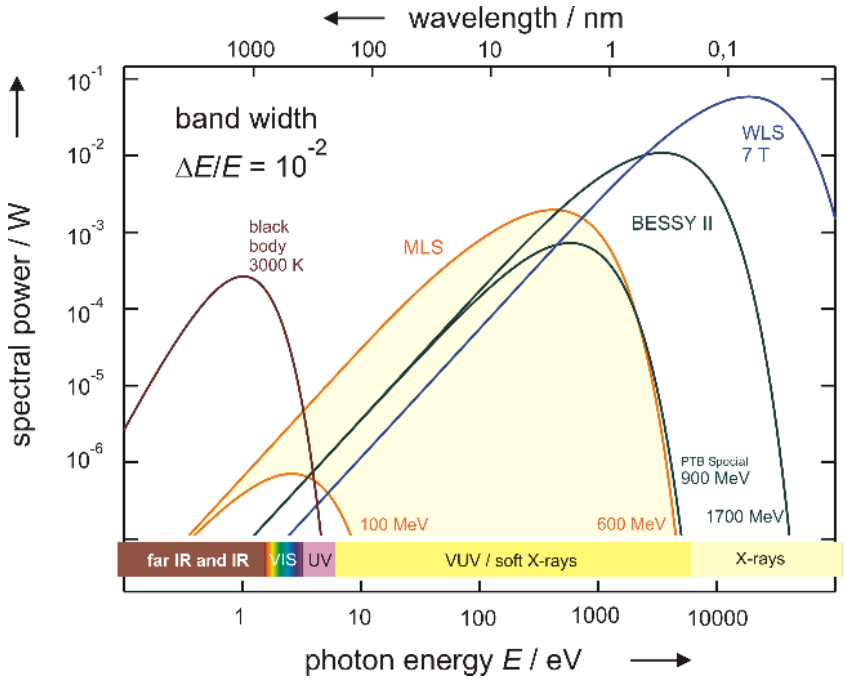


Metrology Light Source

- user operation since 2008
- owned by PTB, designed & operated by HZB
- 38w/a standard operation, 8 weeks special operation

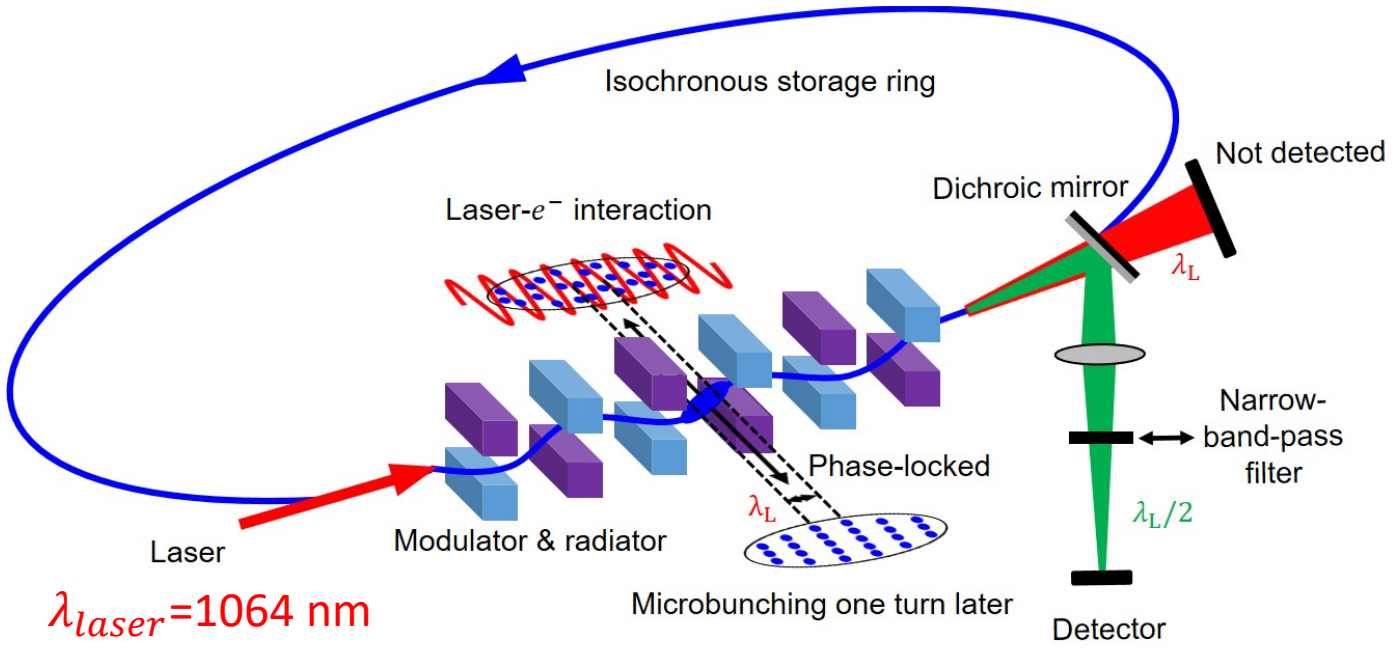
Circumference	**48 m**
Revolution frequency	f_{rev} = 6.25 MHz T_{rev} = 160 ns
Operational Energy	**50 MeV to 630 MeV**
Momentum Compaction Factor	$-5\times10^{-2} < \alpha < 5\times10^{-2}$
emittances at 630/250 MeV	**120**(Standard User)**/30 nmrad** (SSMB)
RF frequency	**500 MHz**
Undulator	**Single U125** λ_u = 125 mm



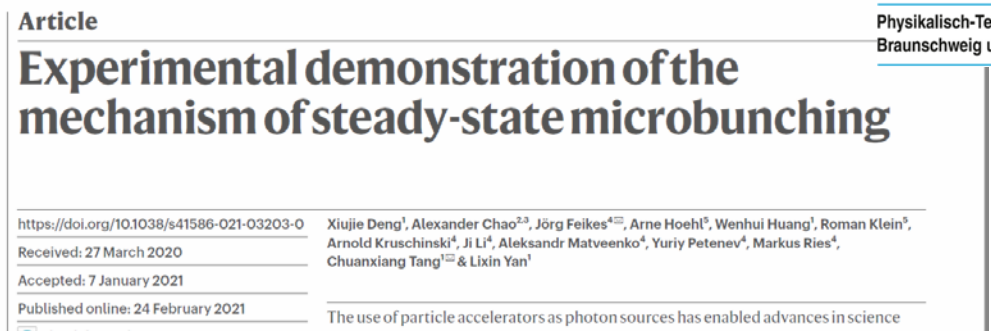


HZB BESSY II Light Source

- first storage ring **optimized for low alpha operation** by using a dedicated sextupole and octupole correction scheme
- unique conditions for experimental ARD towards steady state microbunching
  -> necessary condition for SSMB: **$|\alpha| \leq 2\text{x}10^{-5}$**



critical question:
can a turn-by-turn phase correlation of e- at 1 µm level be maintained in a Storage Ring environment ?
answered by „yes“


Article

Experimental demonstration of the mechanism of steady-state microbunching

https://doi.org/10.1038/s41586-021-03203-0
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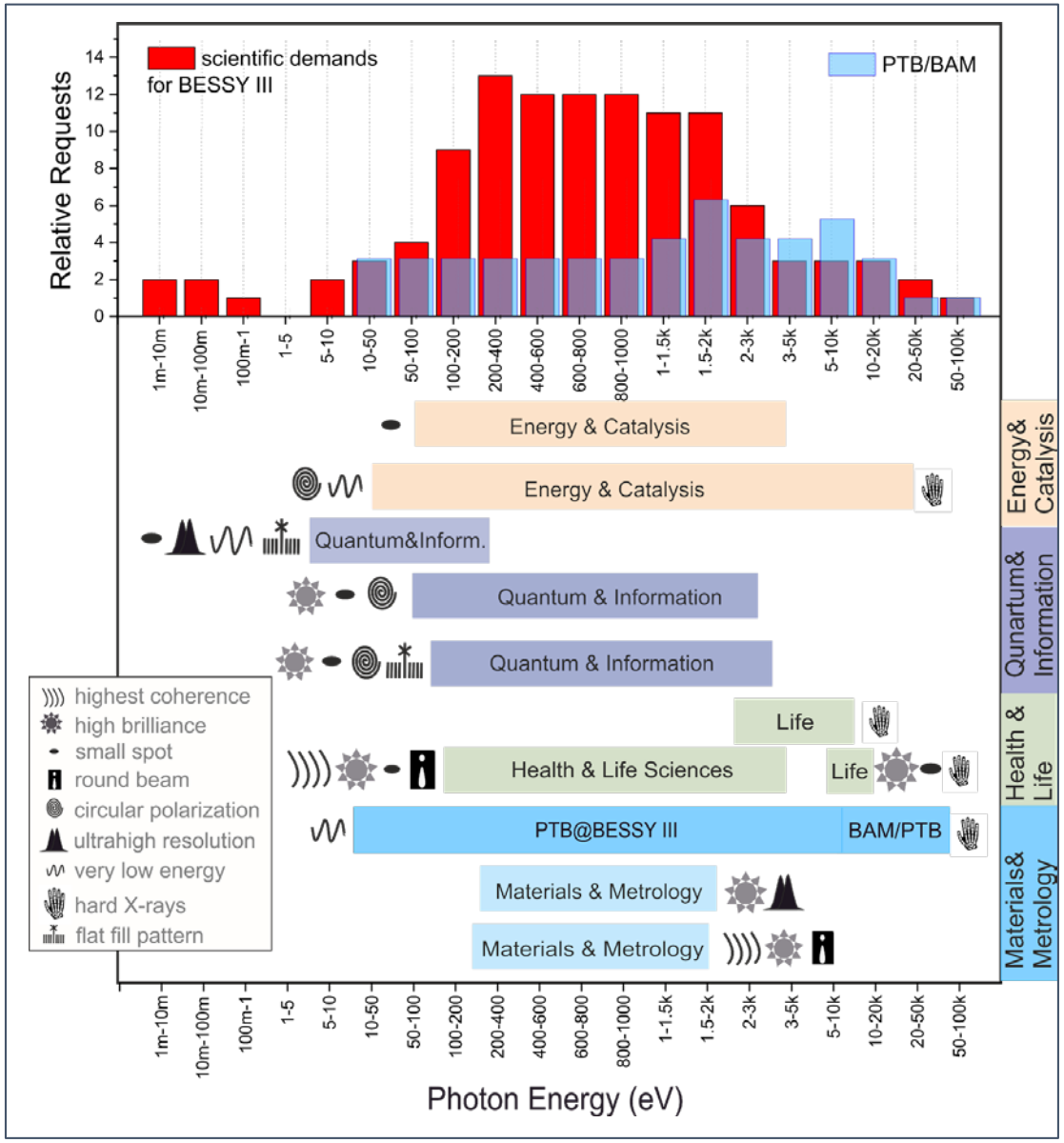
Published online: 24 February 2021

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

Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

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



BESSY III

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

1. Ring Energy **2.5 GeV** (1.7 GeV)
2. Emittance **100 pm rad** (5 nm rad)
3. Circ. **350 m**
   16 straights @ 5.6 m
   (240 m @ 4 m)
4. Low beta straights & Round beams
5. **Metrology – hom. bends**
6. Momentum **> 1.0e-4** compaction factor
   Bunch length **~ 10 ps**

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

Strategy: A robust and reliable system, minimizing technical risks/developments

- Greenfield option allows for minimizing technical risks (also testing in BESSY II)
  - Storage ring : no excessive gradients or complex magnets
    focus on sustainable magnets to reduce power consumption (perm. magnets)

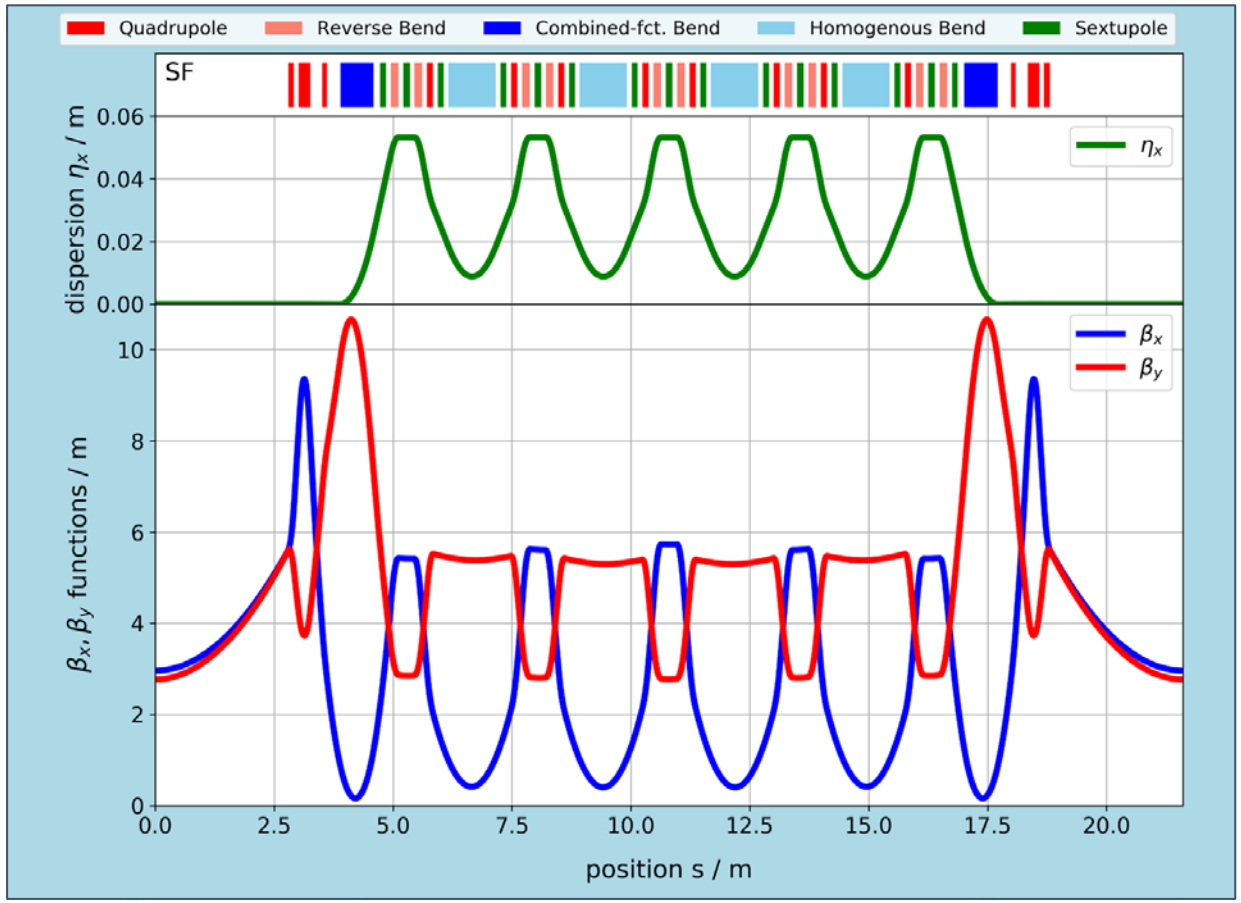
    Sources: spectral range (“polarised”) can be covered with standard APPLE-IIs
    expandable with IVUE
  - Injection: transverse injection based on single, 4- or non-linear kicker injection.
    booster synchrotron in same tunnel as storage ring.
  - RF-System: 500 MHz EU HOM damped cavities and 3rd harmonic cavities
- risky R&D only on side tracks: Double Period Undulator (DOPU), Timing Modes (TRIBs), …

Combined function or Separated function (homogenous bend) Lattice

- BESSY III lattice development is ongoing. Special request: homogenous bend for metrology applications

- two working solutions:
  sf (at least) as good as cf-lattice!
  ⟶ Less chromatic sext. strength
  Indication for better non-linear beam dynamics

- non-linear optimization on the way:
  TSWM, TSWA, DA & LT,
  tolerance studies,
  collective effects,
  injection

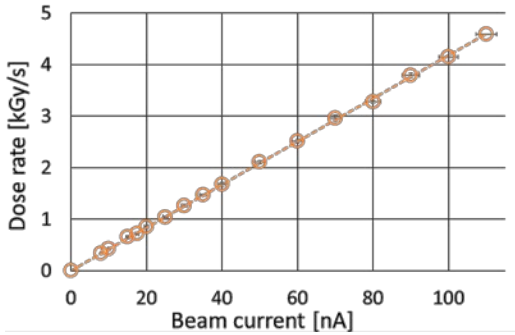


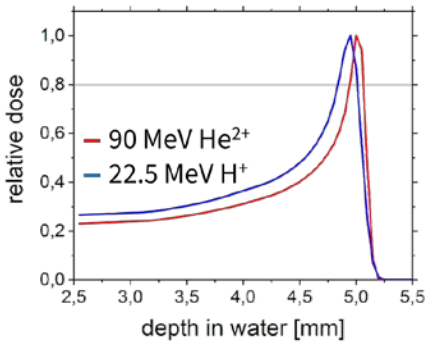
periodic		ok
Periods		16
Length	[m]	350.304
Angle	[deg]	360.000
AbsAngle	[deg]	432.531
TuneA		43.71999
TuneB		12.75999
ChromA		0.008
ChromB		0.003
Alpha	[xE-3]	0.115
JA		2.07985
JB		1.00000
Energy	[GeV]	2.500
EmitA	[nm rd]	0.101
EmitB	[nm rd]	0.0000
dE/turn	[keV]	320.8
Espread	[xE-3]	0.899
TauA	[ms]	8.756
TauB	[ms]	18.212
TauE	[ms]	19.792
Location		END
Position	m	21.894
BetaA	m	3.123
AlphaA		0.0000
BetaB	m	3.022
AlphaB		0.0000
Disp X	m	0.0000
Disp'X	rad	0.0000
Disp Y.	m	0.0000
Disp'Y	rad	0.0000
PhiA/2pi		2.7325
PhiB/2pi		0.7975

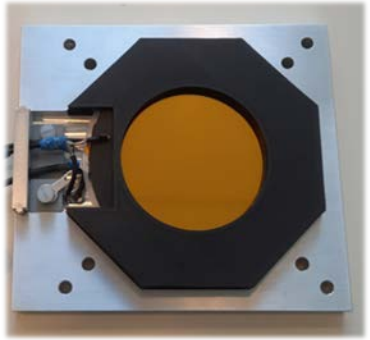
proton therapy

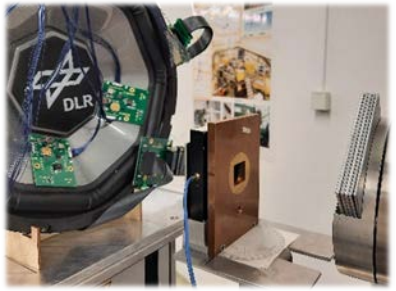
- isochronous cyclotron: ≤ 70 MeV H^+ , $\tilde{I}_{out}$< 1 µA
- operation 9 days/month with 98% uptime for:

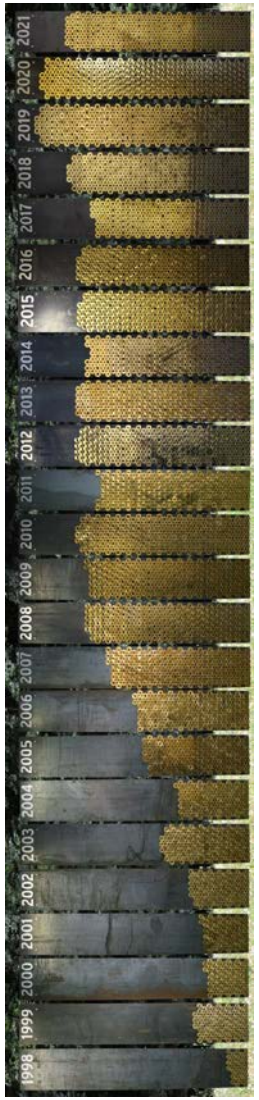
- **Eye-tumour therapy (85%)**
  - collaboration with Charité hospital since 1998
  - > 4300 patients with 96% local tumour control
- **R&D in medical and accelerator physics (10%)**
  - FLASH – ultrahigh dose rate irradiation (ST3) :
  - multiparticle beam delivery (ST2) :
    He^{2+} & stripped H_2^+ with equal dose depth
- **Beamtime for users (5%)**
  - radiation hardness tests for aerospace (solar cells, electronics, optics)
  - detectors, dosimetry, geology, …







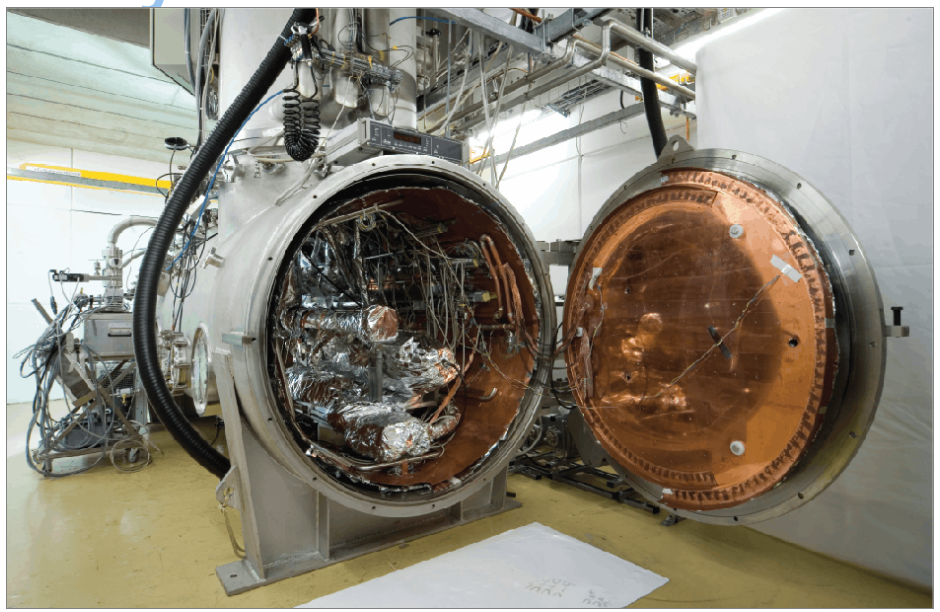




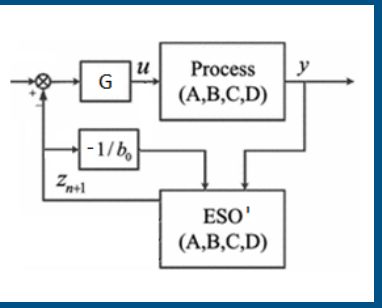
- new end stations coming up, upgrade path under investigation

HoBiCaT- A horizontal SRF cavity teststand

- test fully equipped SRF cavities including helium vessel, motor- and piezo tuner, power couplers, magnetic shielding, etc.
- temperature range down to 1.5 K, typically 1.8 K with 100 W @ 1.8 K: 16 mbar ±30 mbar rms
- RF set up: 1.3 and 1.5 GHz 15 kW SSA, 400 W broadband SSA
- complementary to the vertical test stands for sample testing (Quadrupole resonator) and cavity acceptance tests (critically coupled)



ARD ST3 related measurement campaigns: Tested with TESLA cavity and SRF gun

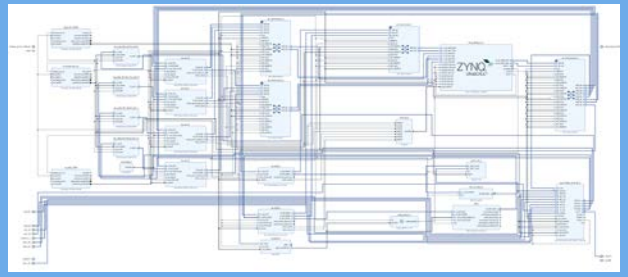


A. Elejaga et al.

Active disturbance rejection control (ADRC)

- Control cavity tuning to compensate microphonics
- Stabilized cavity will improve any longitudinal beam jitter

"RF on a chip" LLRF control system under development

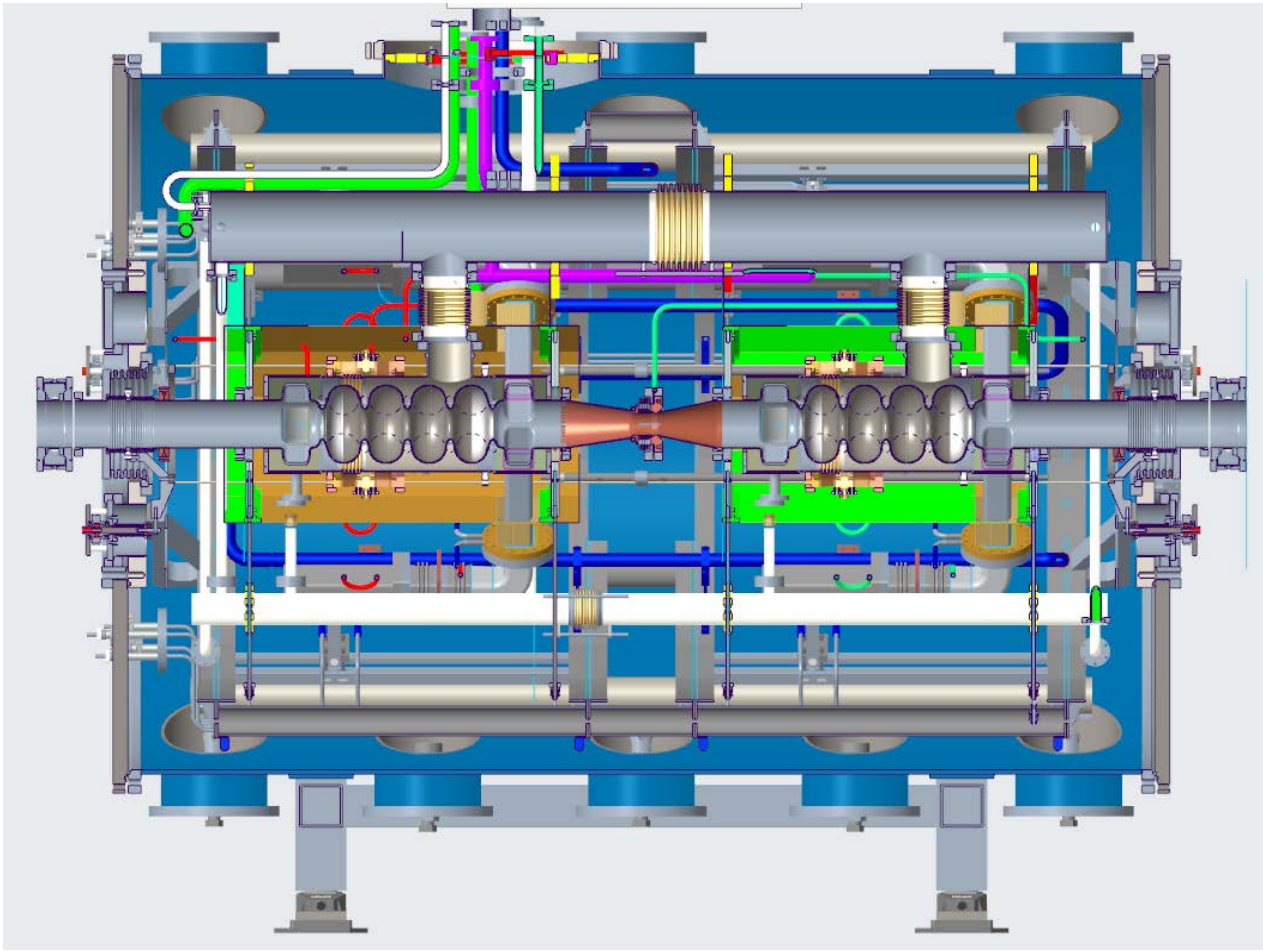


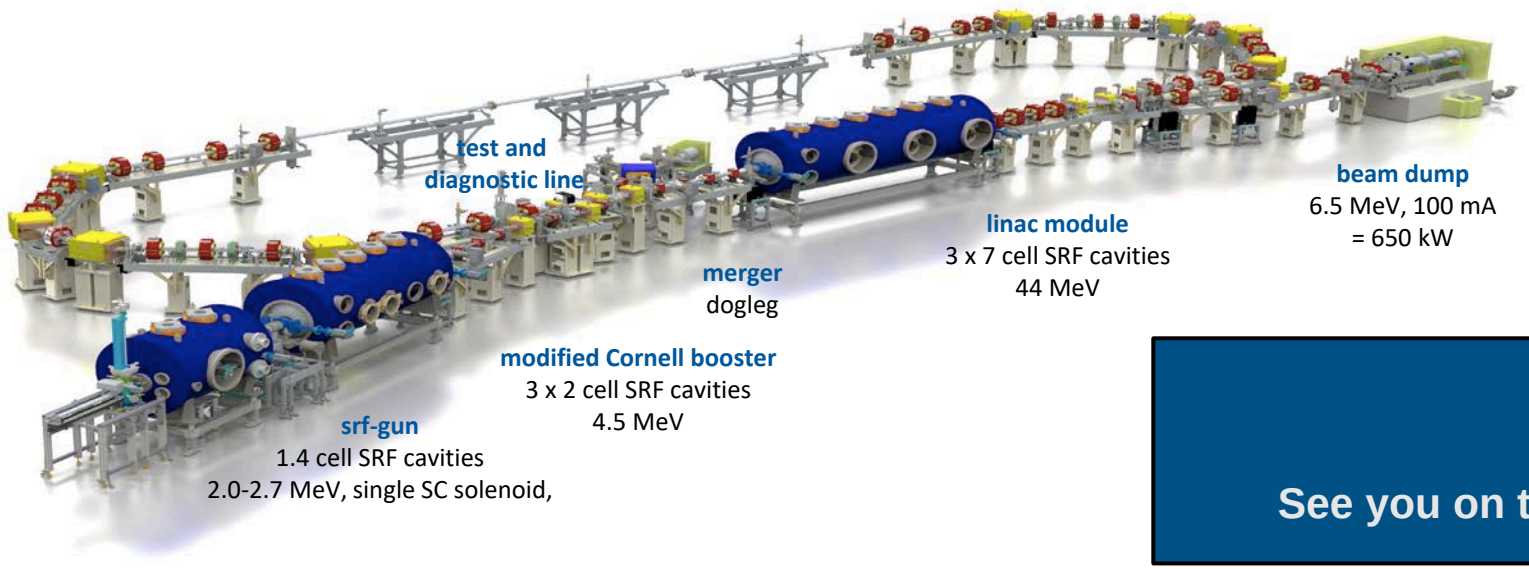
A. Ushakov et al.

- Detuning calculation
- Kalman Filter detuning estimator
- PID controller
- More to come.....

BESSY VSR DEMO

- normal conducting beating keeps the VSR ball in the air
- SC module pursued
- 1.5 GHz cavities being manufactured
- collimated shielded bellow successfully tested up to 400 mA in BESSY II
- warm end groups being tested right now in BESSY II





SEALAB/ bERLinPro

SEALAB

Want to learn more?

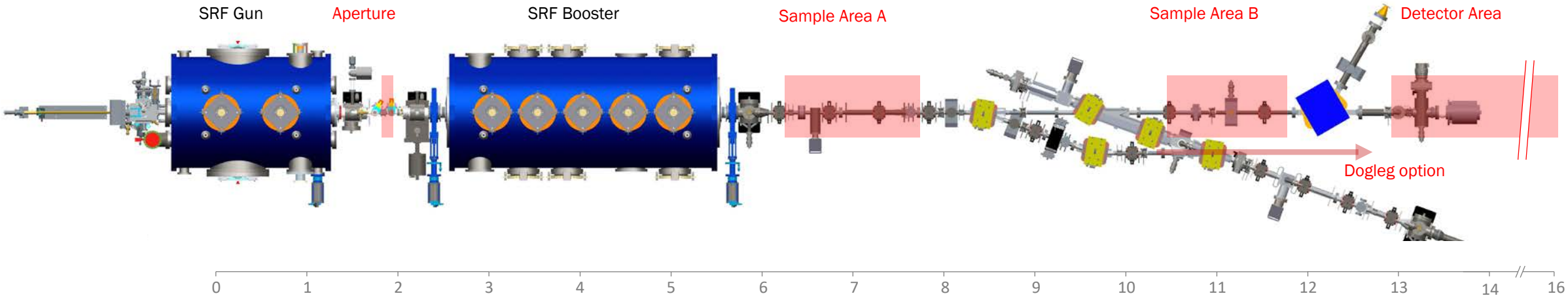
See you on the facility tour on Friday 09.09.2022!

- bERLinPro project accomplished in 2020, readiness of building, infrastructure, warm machine, diagnostics, cryo-plant and high-power RF stations
- Commissioning of SRF photo-injector on-going, high quantum efficiency cathodes preparation , Laser system, high-power RF conditioning of SRF Booster module couplers are on track to allow first beam from the injector spring 2023
- Beam commissioning program in development to map the injector's parameter space from short pulse-low charge to, via medium average currents to high charge regime
- Opening up the machine for additional applications, contributes to the European ERL strategy for HEP

Prospect: ERLs allow efficient operation at high average brightness/luminosity with Linac class beam quality
→ Reduces ecological footprint of large-scale science, especially when combining with higher T_c SRF technology, vision of sustainable large-scale science driver

Ultra-fast scattering experiments with the SRF photoinjector

Many ARD ST1 and ST3 aspects: SRF, beam dynamics, instrumentation, controls, …



Capabilities of the photoinjector:
1 to 3.5 MeV beam energy with **variable** bunch charge (1 fC to 100 pC), pulse length (10 fs to 6 ps) and spot size (10 to 100s µm), **high stability at MHz repetition rate.**

Very **flexible longitudinal accelerator/lens system**: one gun cavity and three booster cavities, done optimization for bunching scheme, see talk on Friday by Benat [1].

[1] B. Alberdi, et al, Sci. Rep. 12, 13365 (2022)

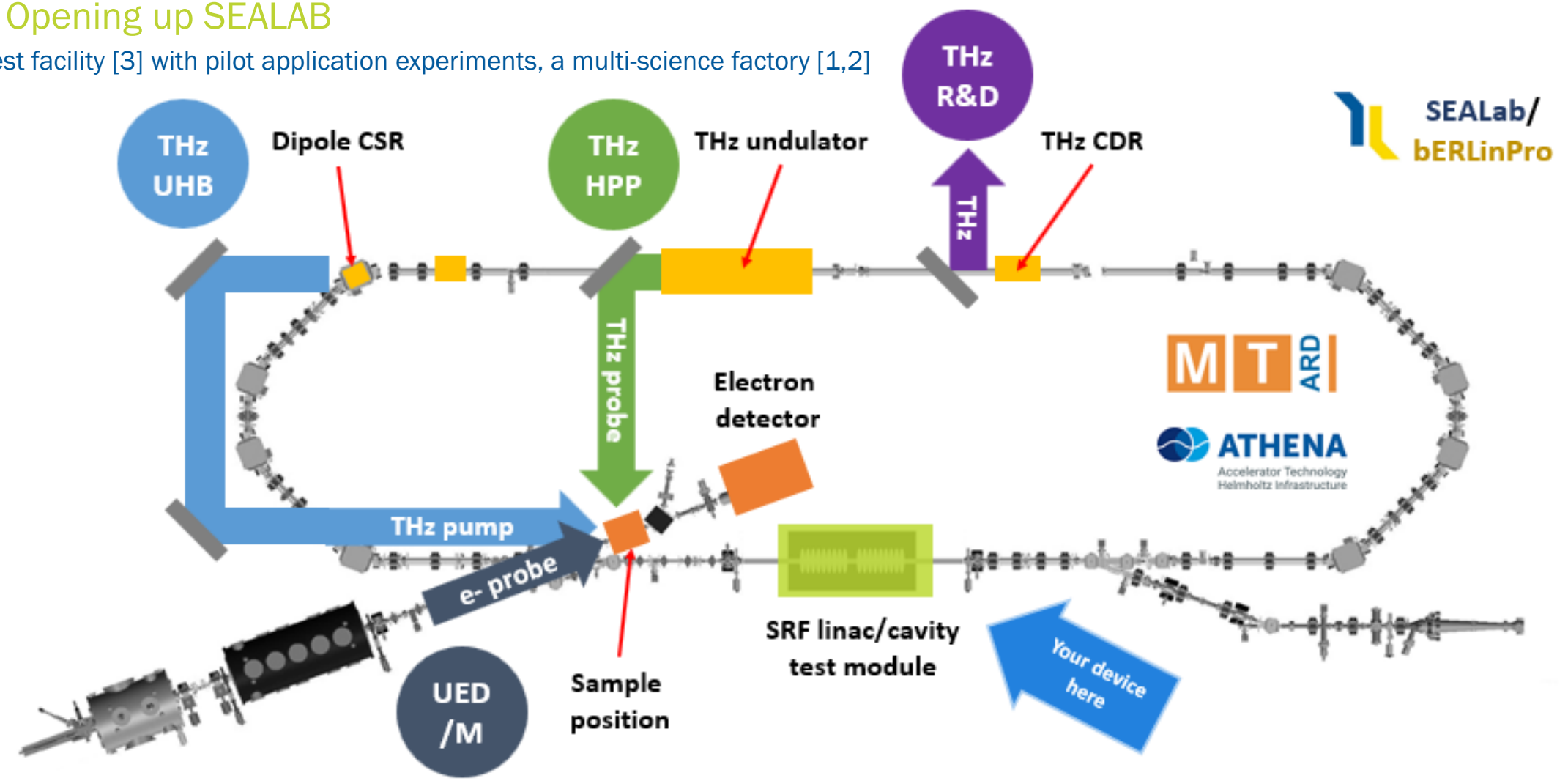
Ultrafast science drivers:
Diffraction camera for **molecular movies** with MHz repetition rate (UED).
Imaging of **macromolecular structures** in liquid phase (UEI).

Complementary to SR and FEL light sources.
Enabling **multi-modal capabilities** for Bessy II/III.

HZB BESSY II Light Source

The dream: Opening up SEALAB

An accelerator test facility [3] with pilot application experiments, a multi-science factory [1,2]

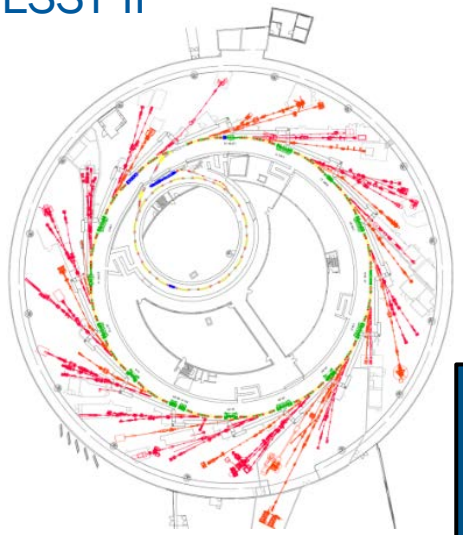


[1] T. Kamps et al., arXiv:1910.00881v2 [physics.acc-ph] 8 Jan 2020

[2] J.-G. Hwang et al., J. Korean Phys. Soc. 77, 337–343 (2020). https://doi.org/10.3938/jkps.77.337

[3] A. Neumann et al., IPAC 2022

BESSY II



Cyclotron &
Proton Therapy
(eye tumours)

HZB Helmholtz Zentrum Berlin

BESSY III

& MLS2

an exciting place to be and to collaborate with

MT ARD | MT DMA

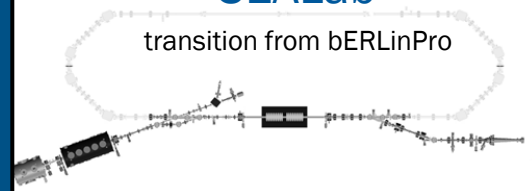
Advanced CW SRF
New Concepts and Prototypes
Advanced Beam Control, Diagnostics, Dynamics

ATHENA, InnoVEA, ACCLAIM

FLASH therapy, radiation hardness in MML

SEALab

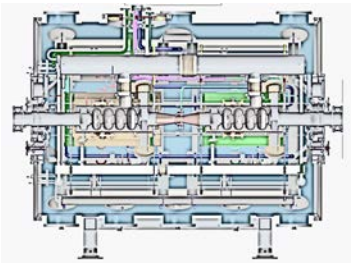
transition from bERLinPro



MLS

PTB

DEMO



LEAPS League of European Accelerator-based Photon Sources

Digital LEAPS – ML, AI, Data
PerMaLic – permanent magnets
HarmonLIP – higher harmonic cavities

SupraLab@HZB

HZB BESSY II Light Source

Many thanks to all contributors of slides:

Andreas Jankowiak, Jens Völker (perm. magnets), Jörg Feikes (MLS), Paul Goslawski (BESSY III), Thorsten Kamps and Axel Neumann (SEALAB and HOBICAT), Adolfo Velez (BESSY VSR DEMO), Greorgios Kourkafas (proton therapy)

and all HZB and PTB staff contributing to ARD activities

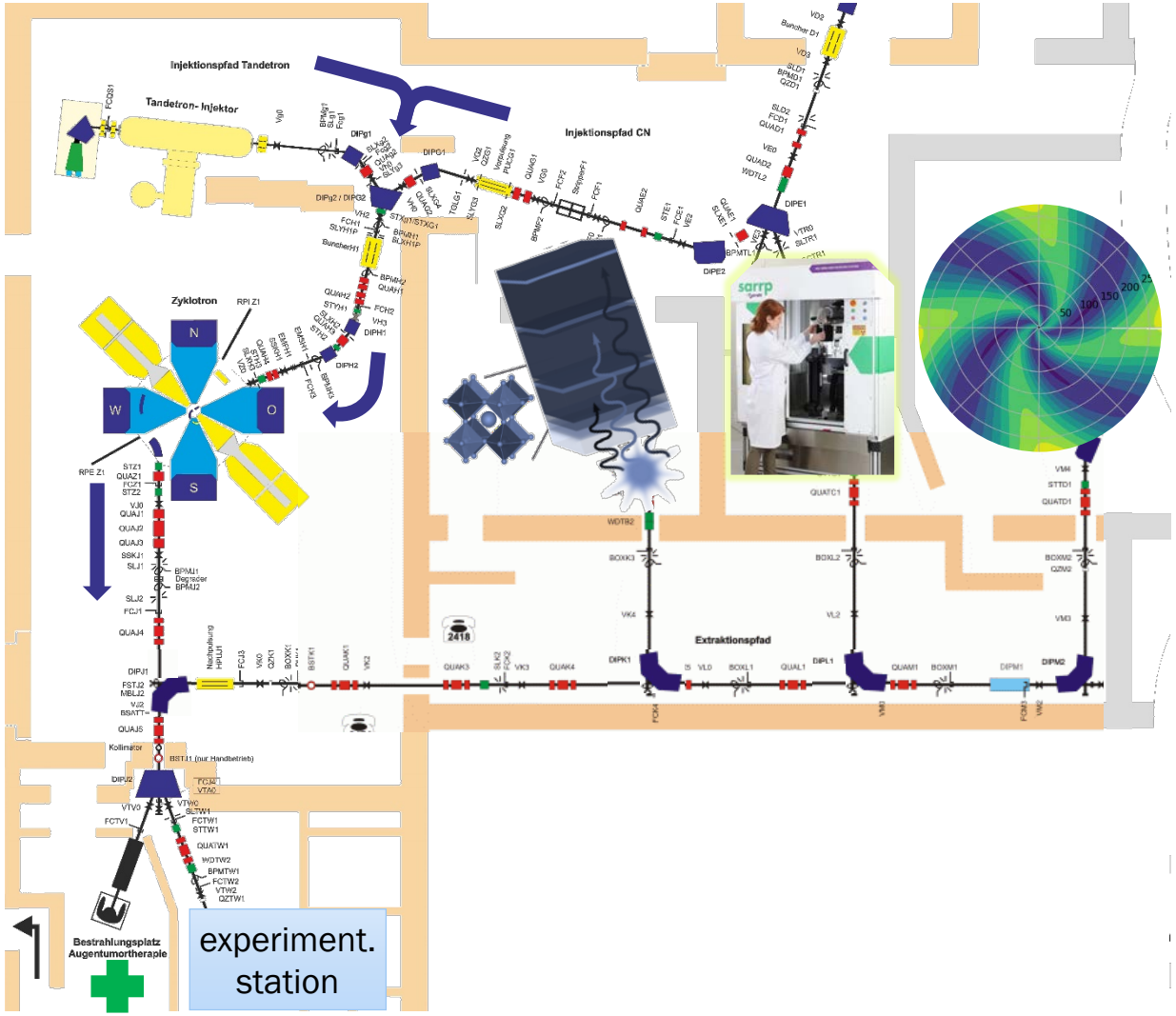
and all contributors to this workshop

for your attention

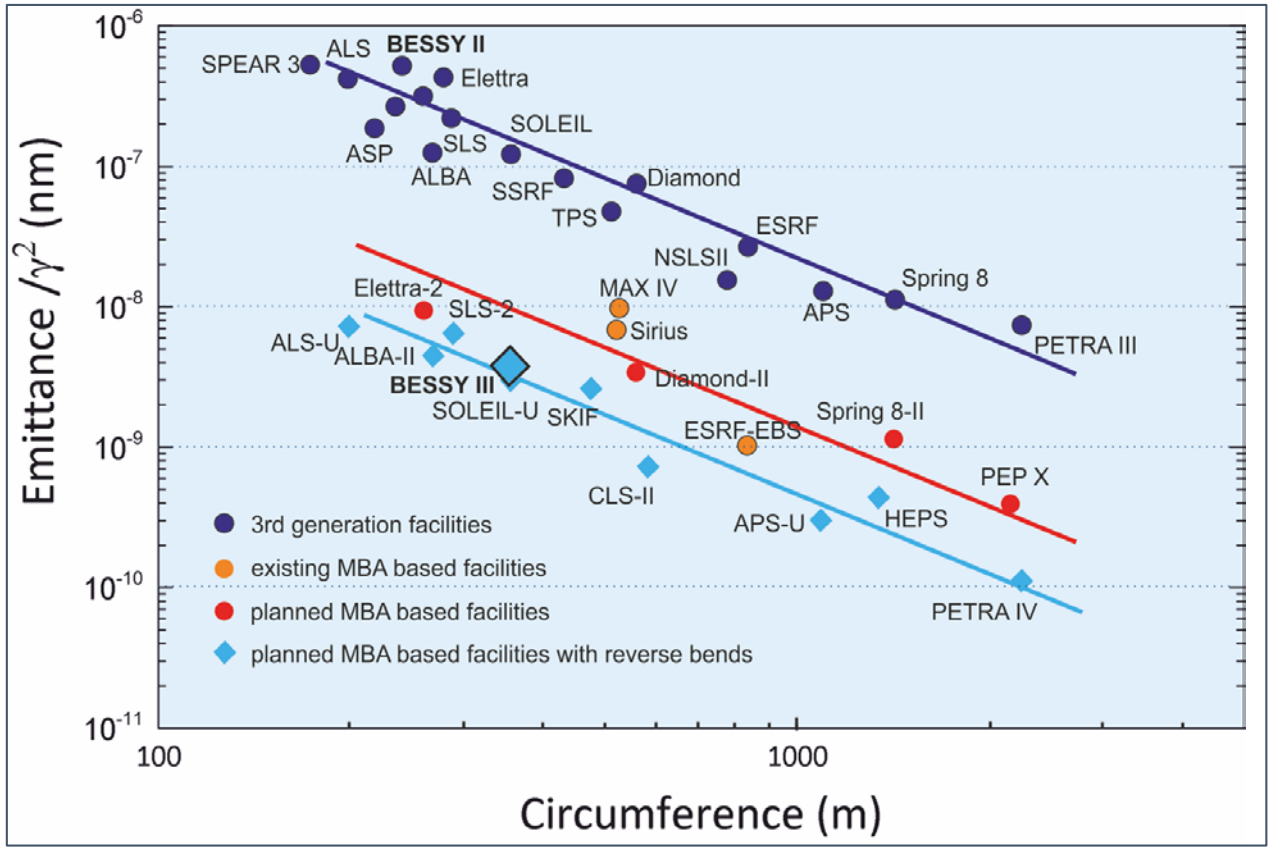
BACKUP

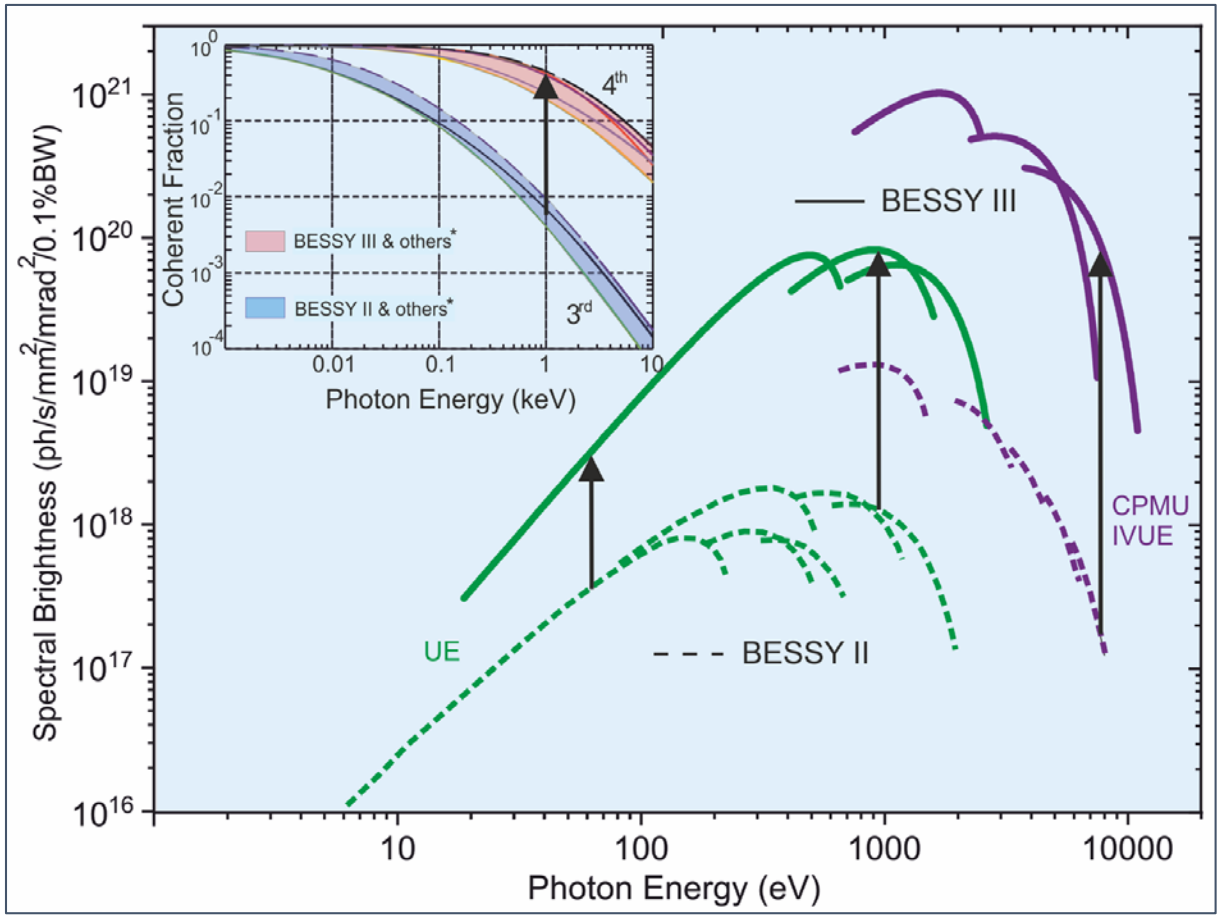
- **New end-stations**
  - radiation-tolerant electronics with soft semiconductors (TU Potsdam)
  - minibeam radiotherapy (UniBw)
  - beamline extension

- **Upgrade plan**
  - 3-year project to secure longevity of eye-tumour therapy
  - therapy cannot be interrupted – long shutdown not possible!
  - successor accelerator investigated:
    - compact design
    - incorporating FLASH & He therapy
    - potential for commercialization
  - implementation in existing building or green-field solution considered



BESSY III
100X TIMES MORE BRIGHTNESS THAN BESSY II &
1000X TIMES SMALLER FOCUS AT SAMPLE (10MM DOWN TO 10NM)

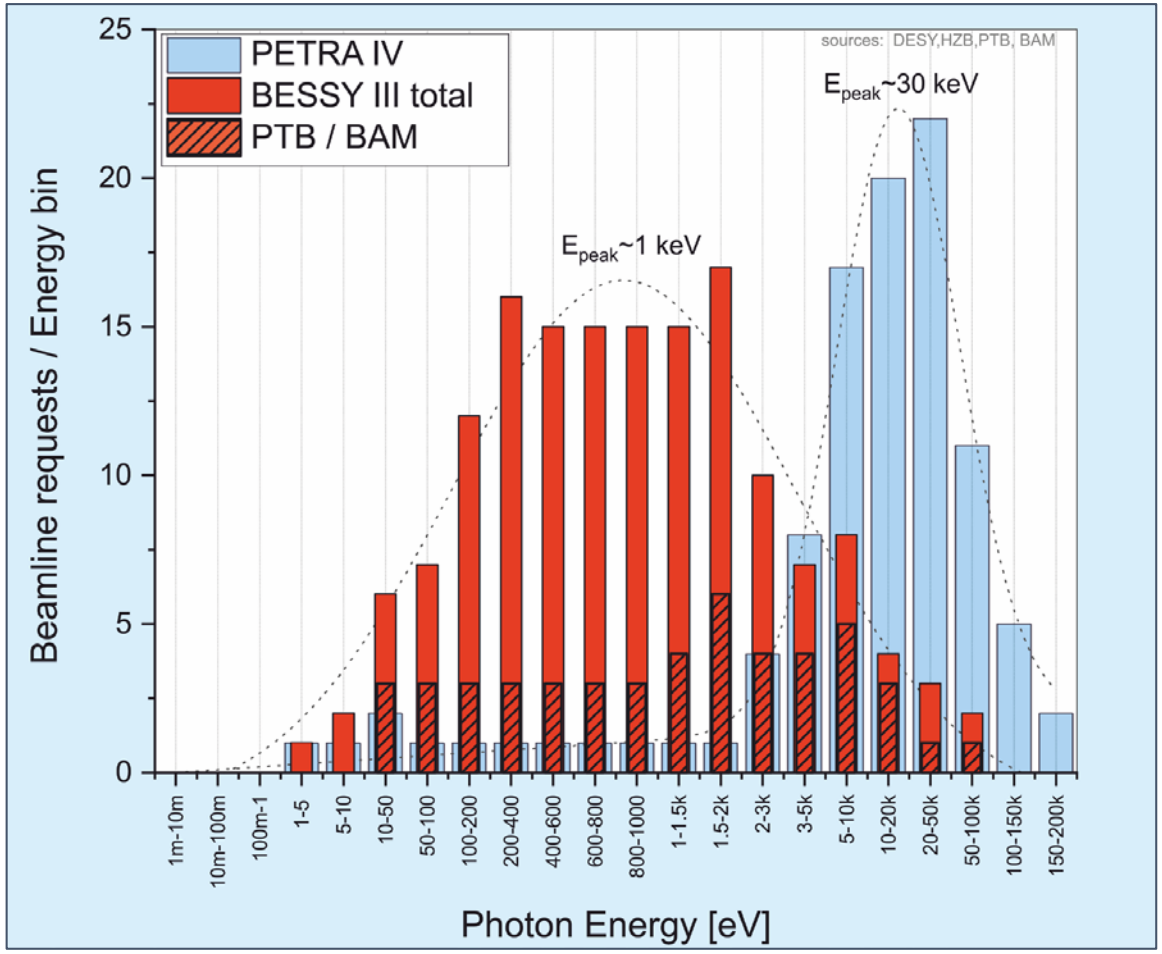




In situ - in operando, sample environment, Labs → Integrated Research Facility

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	BEIChem, XPS BEIChem, 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 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, µCT	Materials Metrology Materials Metrology