HZB BESSY II Light Source

Development of the In-vacuum APPLE II Undulators at HZB

Atoosa Meseck

FLS 2023, 31.08.2023

FLS 2023
Lucerne 27.08.-01.09

ACKNOWLEDGEMENT

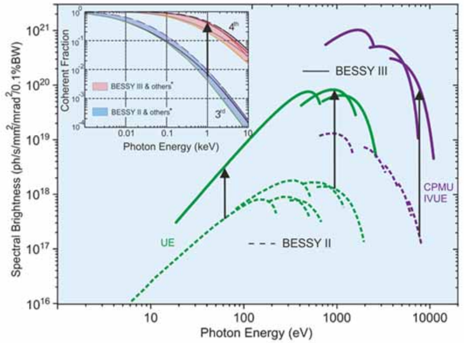
Johannes Bahrdt, Jürgen Bakos, Guilherme Carrera, Winfried Frentrup, Simon Gaebel, Stefan Gottschlich, Stefan Grimmer, Maryam Huck, Kiarash Karimi , Sebastian Knaack, Carsten Kuhn, Florian Laube, Oliver Reichel, Christoph Rethfeld, Edward Rial, Anette Rogosch-Opolka, Michael Scheer, Bodo Schulz, Mario Strehlke and Paul Volz

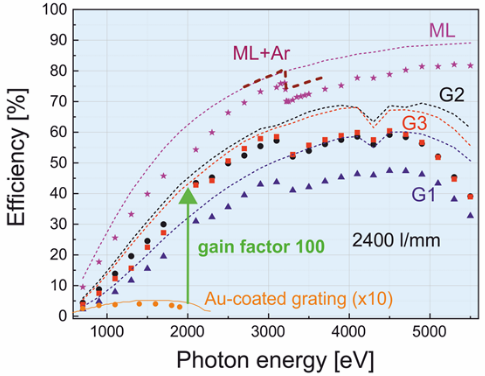
MOTIVATION

BESSY III is envisaged as a world leading facility for materials discovery:

- competitive 4th generation synchrotron radiation source
- embedded in the integrated research campus Berlin-Adlershof
- dedicated to metrology and quantitative materials science

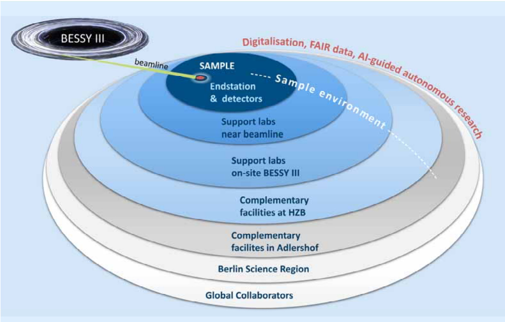
Storage Ring, IDs and BLs tailored for improved brilliance and coherence

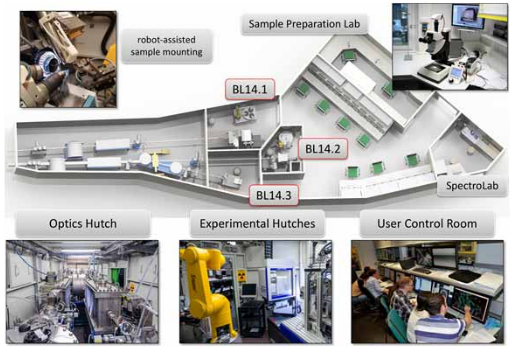




BESSYIII Parameters	
Energy	2.5 GeV
Circumference	~ 350 m
#of straights	16 (each 5.6 m)
Emittance	100 pm rad
$\beta x,y$ in straights	~ 3 m, 3 m
Stored current	300 mA (500 mA)

Experimental instrumentation and infrastructure – an integrated approach





For more on BESSY III lattice in this Workshop see please:

TU1B1, „A Highly Competitive Non-Standard Lattice for a 4th Generation Light Source with Metrology and Timing Capabilities"

WE4P31, „Deterministic Approach to the Lattice Design of BESSY III"

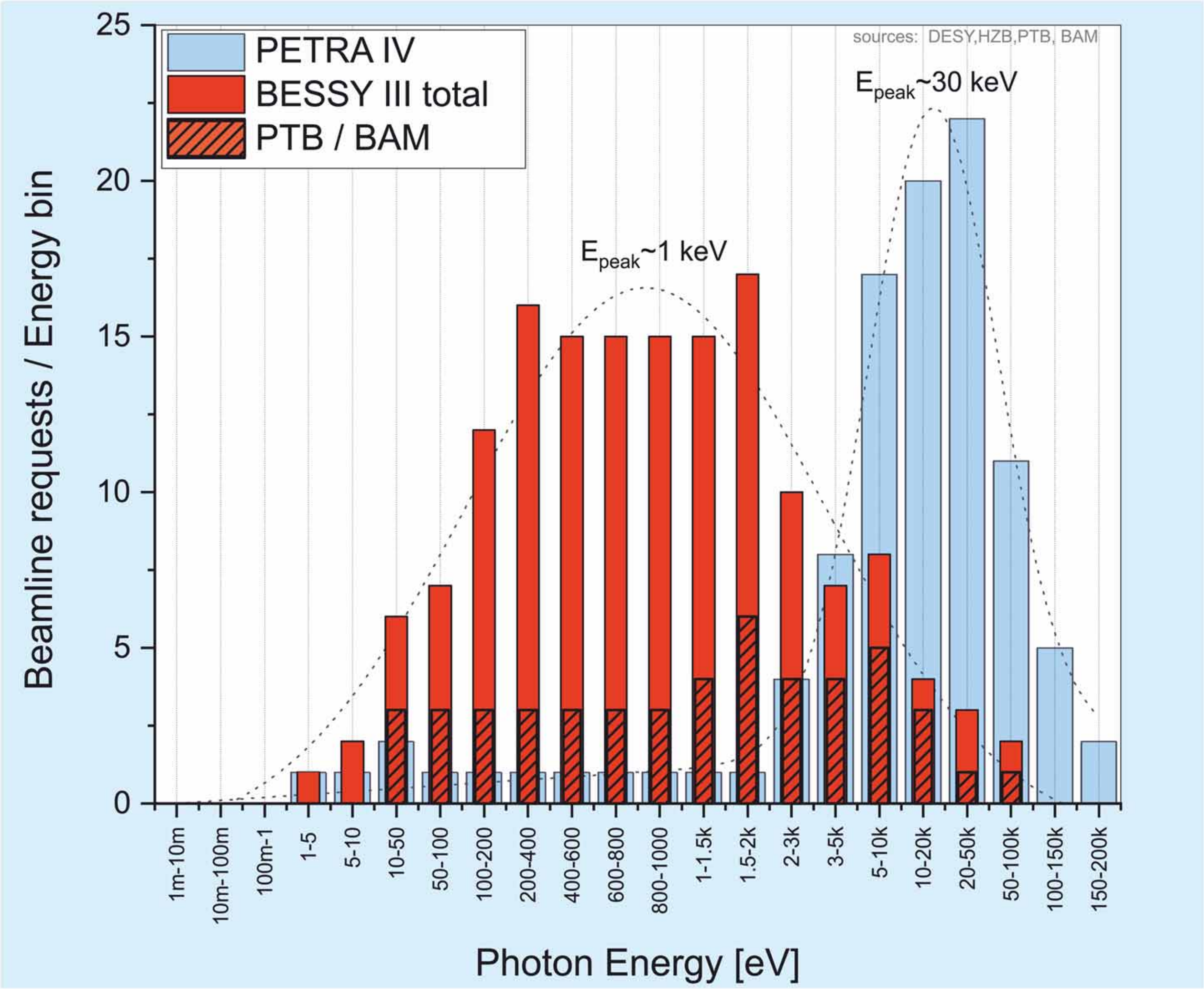
MOTIVATION

The beamline request translates to following requirements for IDs:

- A broad spectrum, with a core range from soft-to-tender X-ray energies.
- Full polarisation control for ever higher photon energies.

Goal

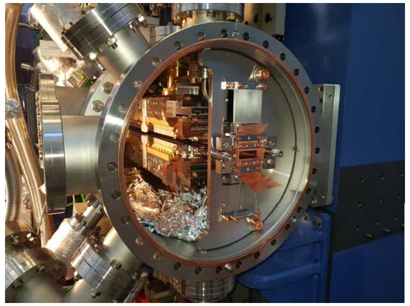
- Design and build insertion devices that will provide each beamline with a high flux, high spectral brightness and coherence tailored to their experimental requirements.



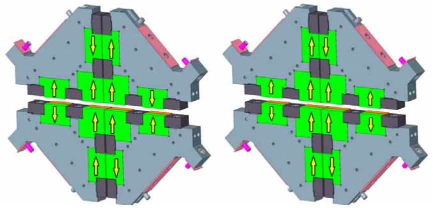
APPROACH

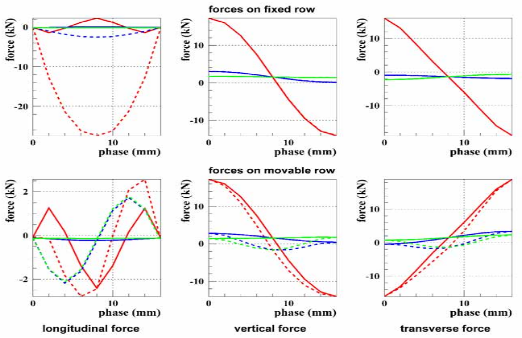
Use of a wide variety of established and developing ID technologies:

- CPMUs for the tender X-ray range.
- APPLE-II (in-vacuum and in-air) and planar devices for the soft X-ray range.
- APPLE-KNOT or APPLE-LEAF type undulators for the VUV and soft X-ray.
- Novel Multi-Period Undulators for beamlines that require access to the very broadest spectrum BESSY III is able to offer.
- Provide Dipoles and WLS for BAM and PTB.

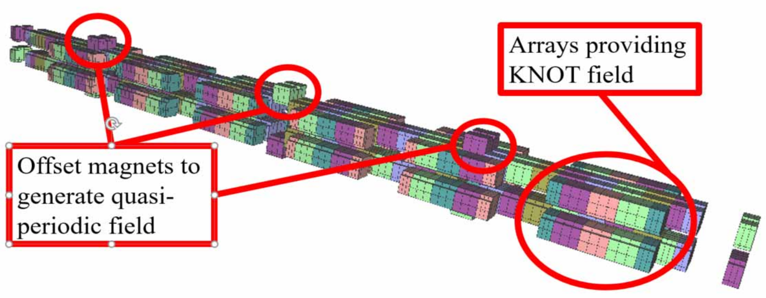


CPMU 17

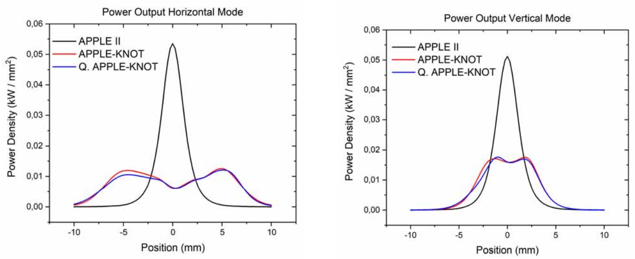




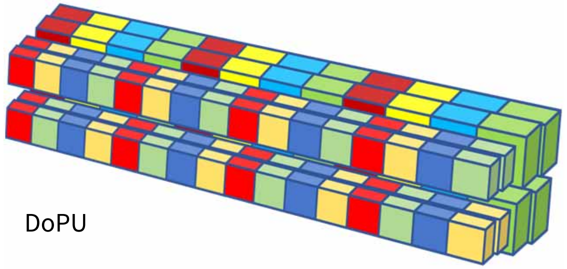
Force compensation; *J. Bahrdt, S. Grimmer, SRI 2018, Taipeh, Taiwan*



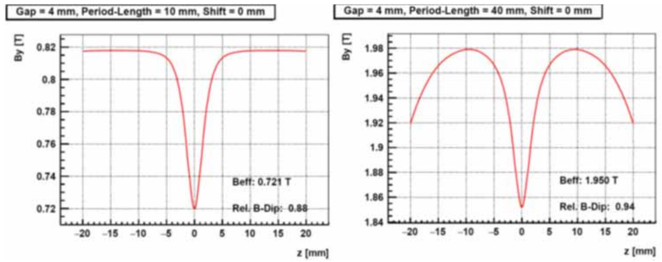
A RADIA model of a quasi-periodic APPLE-KNOT undulator.
E. Rial et al. , IPAC2023, Venezia, Italy-



Comparison of power output between a conventional APPLE II device, and both normal and quasiperiodic APPLE-KNOT devices, in horizontal and vertical polarisation modes.



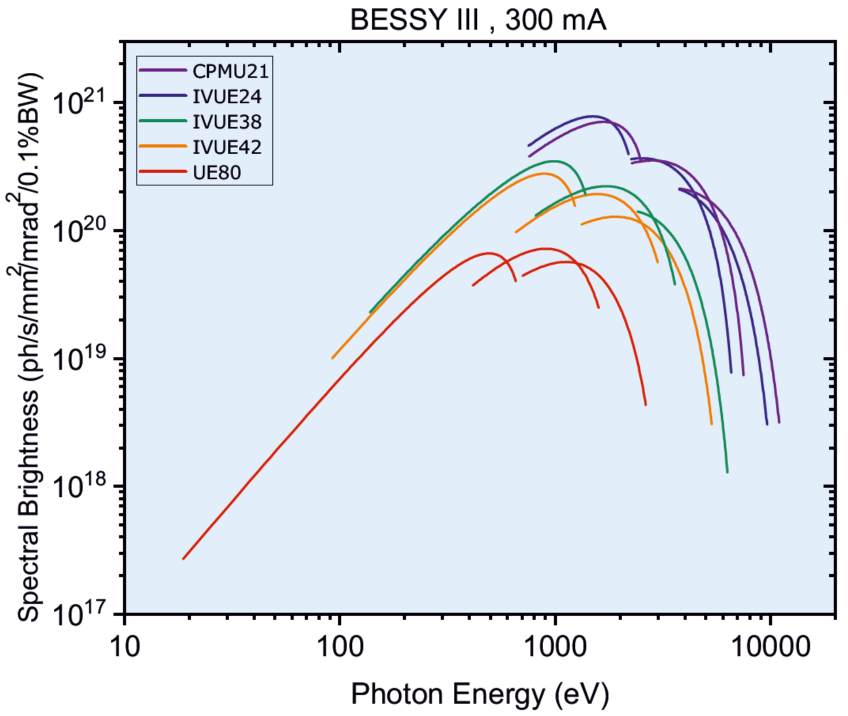
DoPU

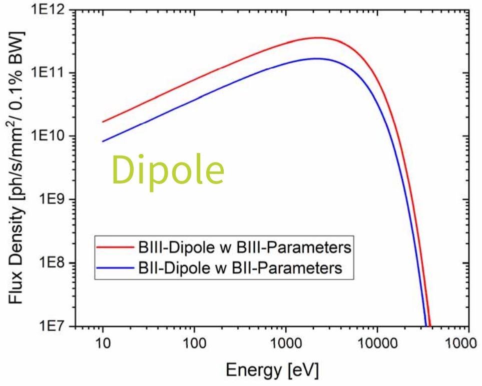


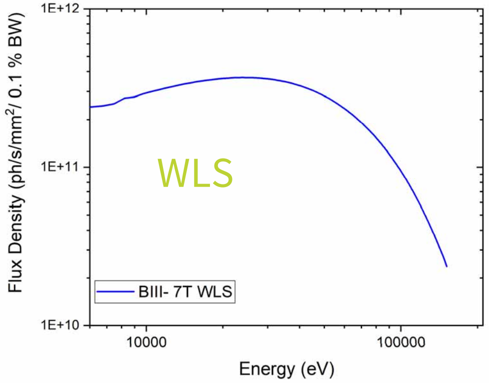
INITIAL PROPOSAL

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

- **U are planar devices and UE are APPLE-II devices.**
- **CPMU are cryogenic planar in-vacuum devices.**
- **IVUE are in-vacuum APPLE-II devices.**
- **The period length in mm is specified in the name of IDs.**
- **The minimum gap for all in-vacuum devices (IVUEs and CPMUs) is 6 mm.**
- **A minimum gap of 13 mm is assumed for UE80.**
- **CPMU21 is 3.5 m long. All other IDs of BESSY III are assumed to be 5 m long.**







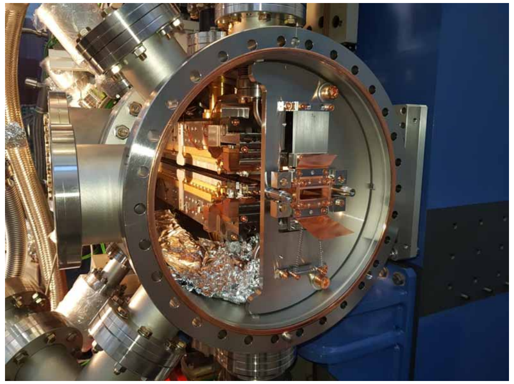
RECENT DEVELOPMENTS

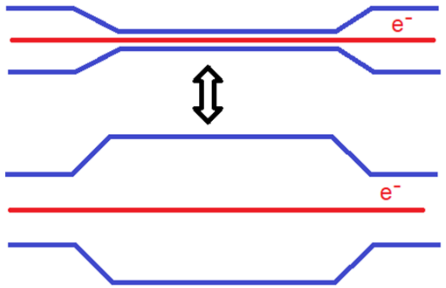
Wakefields and Impedances

Short Period In-Vacuum Devices

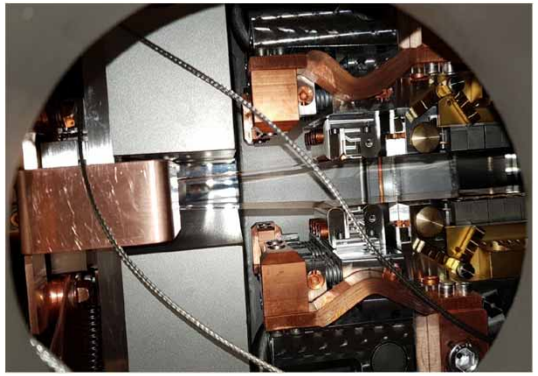
- Development, construction, commissioning and operation of the **Cryogenic Permanent Magnet Undulator (CPMU17).**
- Development, design and construction of an in-vacuum measurement bench.

CPMU 17 in Operation since 2018





Movable gap of in-vacuum IDs can change between collimator and cavity



- Wakefields of charged particle beams interact with vacuum chamber components
- Complex tapers are required for the transition between beam pipe and magnet rows can influence beam dynamics and heat components
- Understanding impedance is vital for accelerator operation

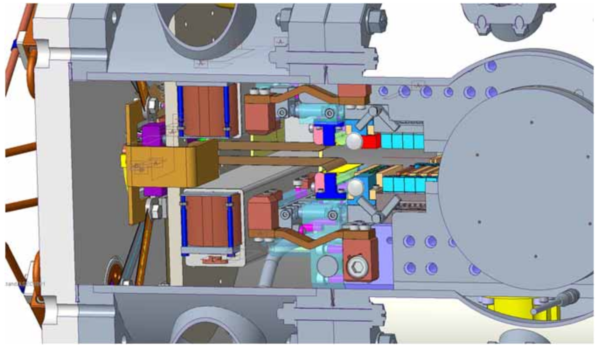
We observe some heating in taper section , that depends on the bunch length

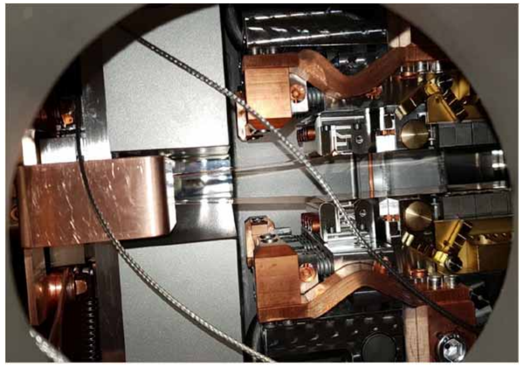
M. Huck et al, in IPAC2021, Campinas, SP, Brazil

RECENT DEVELOPMENTS

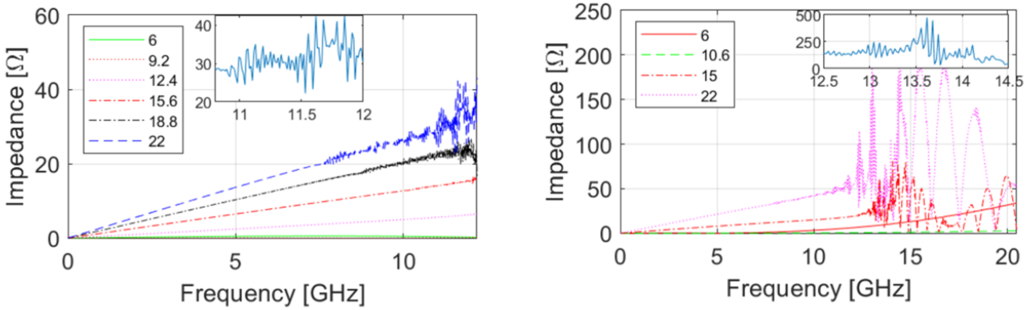
Wakefields and Impedances

Cryogenic Permanent Magnet Undulator (CPMU17).



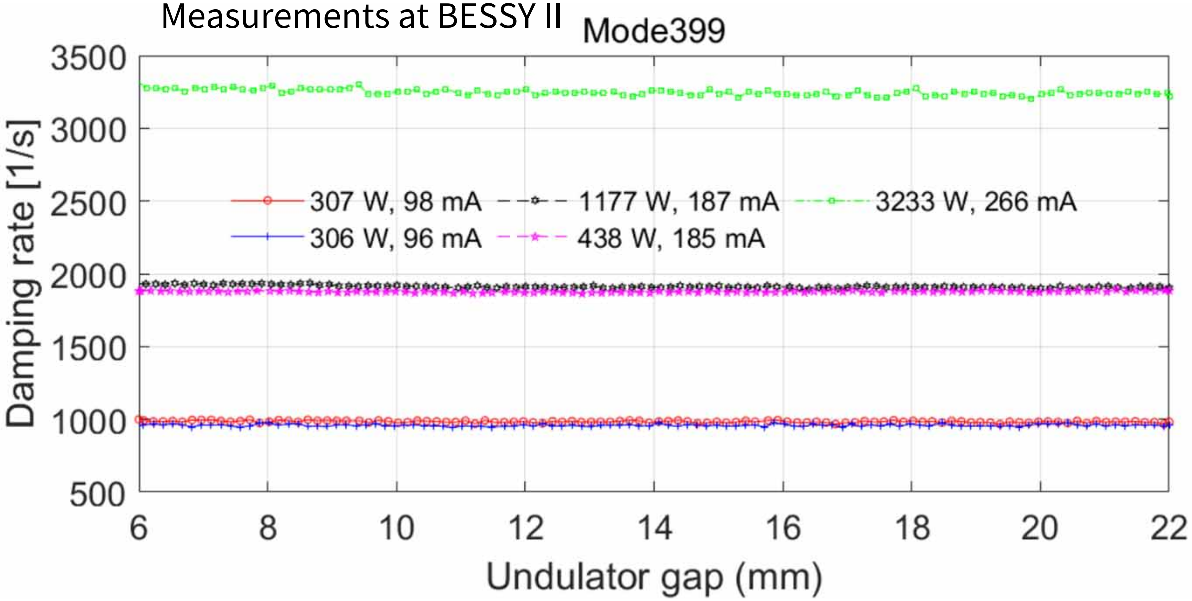


We observe some heating in taper section , that depends on the bunch length. In agreement with Simulation.



$Z_z(\nu)$ for several gaps with 8.4 mm (left) and 5 mm (right) bunch.
M. Huck et al, in IPAC2021, Campinas, SP, Brazil

Measurements at BESSY II

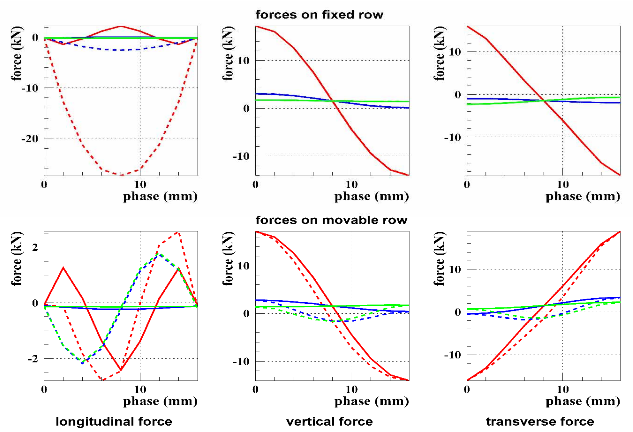


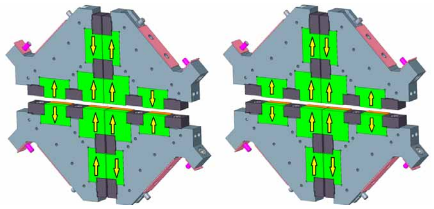
Extensive grow-damp studies (in three planes) and drive-damp studies (in vertical plane), using two different feedback systems

→ **no changes to transverse coupled bunch damping could be observed for variation of the CPMU17 gap.**

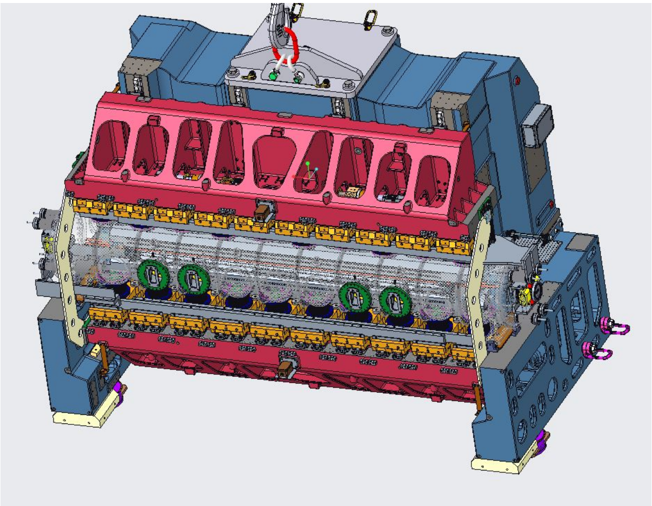
M. Huck et al, in IPAC2021, Campinas, SP, Brazil

DEVELOPMENT OF THE IN-VACUUM APPLE II UNDULATOR IVUE32



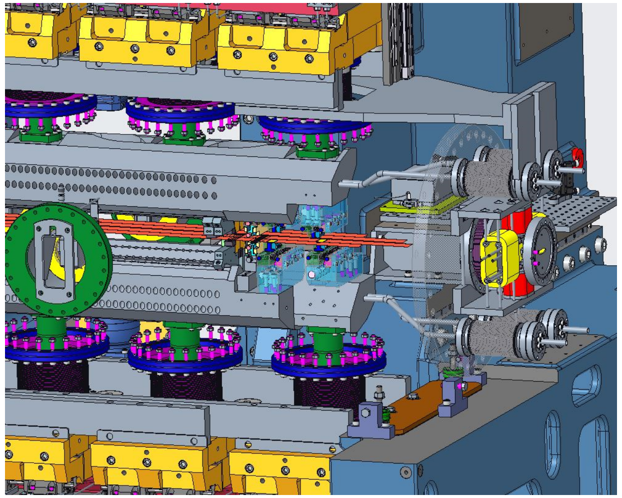


Force compensation; J. Bahrdt, S. Grimmer, SRI 2018, Taipeh, Taiwan



- Based on force compensation
- Complete motion control system is placed in air => standard components
- Reduced stiffness of the magnet structure

  => force compensation
- Magnet gluing replaced with a UHV-compatible soldering technique.
- Gap and shift motion measured via optical micrometer (like CPMU17)
- Construction of corresponding test benches is ongoing.



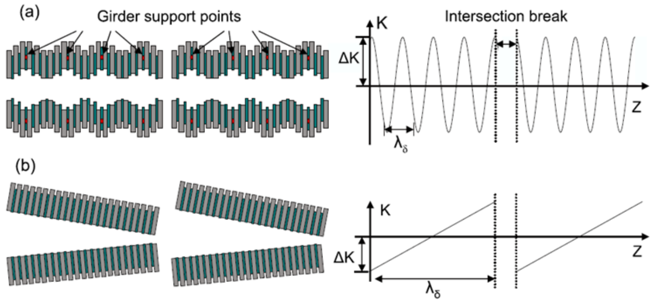
Period length / magnetic gap	32 mm / 7mm
Total length of periodic part	2.5 m
Number of periods	78
Vertical / circular / horizontal field	1.011 / 0.887 / 0.803 T

Phase Shimming; J. Bahrdt et al. in SRI 2021

DEVELOPMENT OF THE IN-VACUUM APPLE II UNDULATOR IVUE32

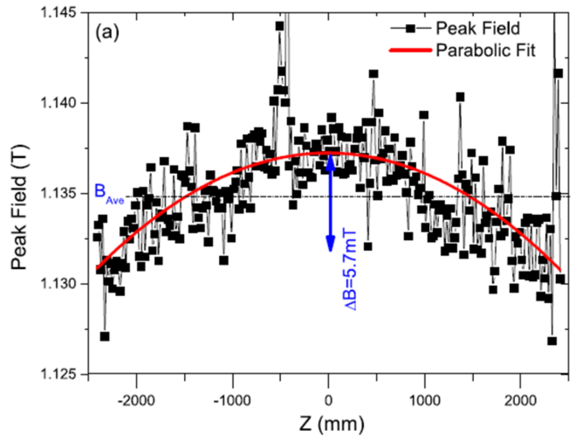
Phase Errors in In-Vacuum APPLE II IVUE32

PRST 2008, $\Delta K = half\ error\ range$



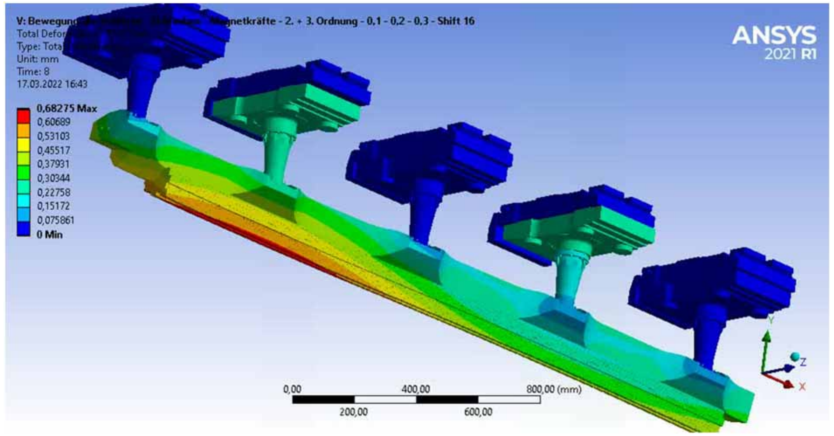
Y. Li, B. Faatz, J. Pflueger, PRST-AB 11, 100701 (2008)
Y. Li, B. Ketenoglu, J. Pflueger, PRST-AB 18, 060704 (20
(slightly different parameter definition in the papers)

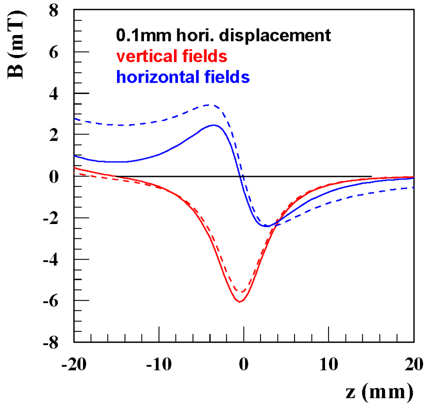
PRST 2015, $\Delta K = full\ error\ range$

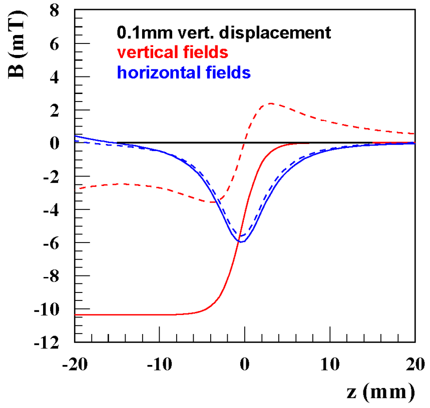


Gap consideration for planar IDs ⇒ Slit variation in InVacuum-APPLE

FEM-based evaluation on load of relevant parts







solid: field change , dashed: field integral change

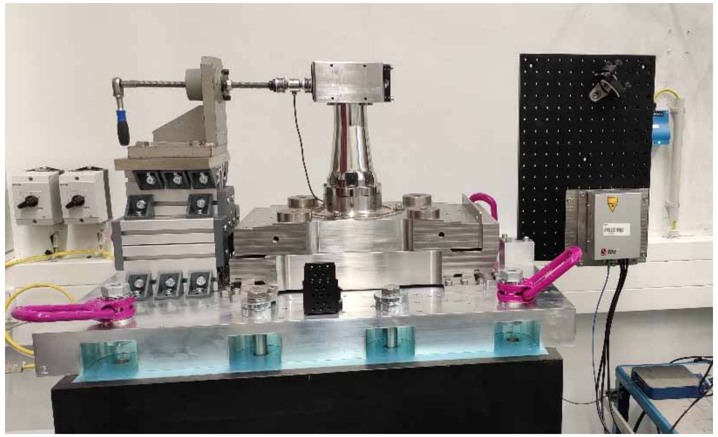
- Field integral changes are decoupled on-axis
- Field changes are only for horizontal magnet row movement on-axis decoupled

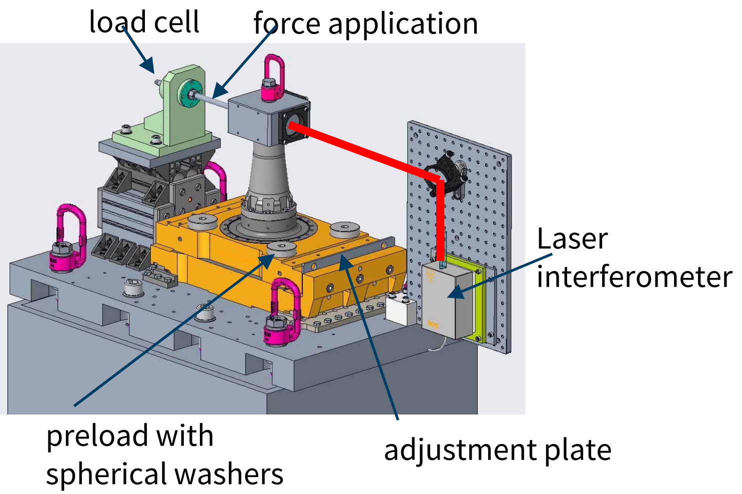
Strategy:

- Vertical gap accuracy achieved via fabrication precision (demonstrated with CPMU17)
- Slit uniformity between magnet rows adjusted with transverse slides

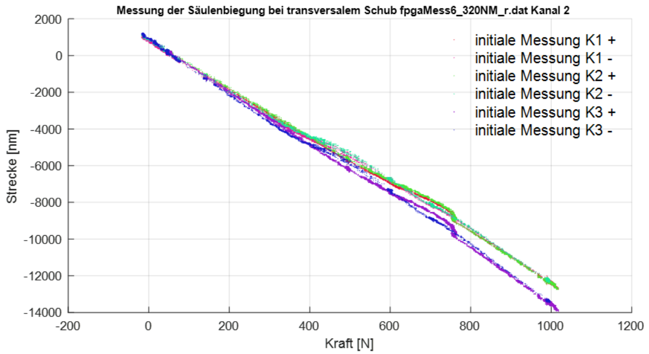
DEVELOPMENT OF THE IN-VACUUM APPLE II UNDULATOR IVUE32

Stiffness Test of Prototype Transverse Slide





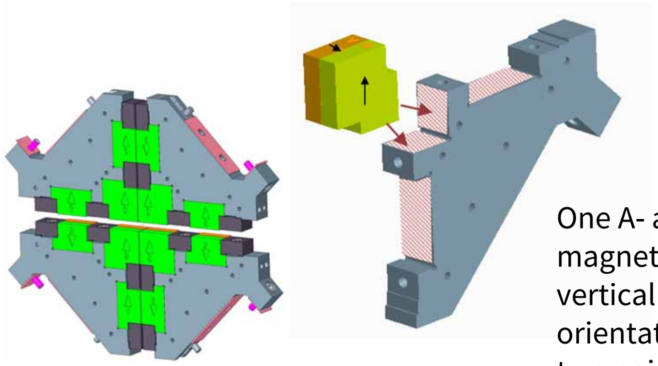
The slide prototype was subjected to a force of ~1000 N from each side. In both cases, the displacement was measured with the 3-beam interferometer.



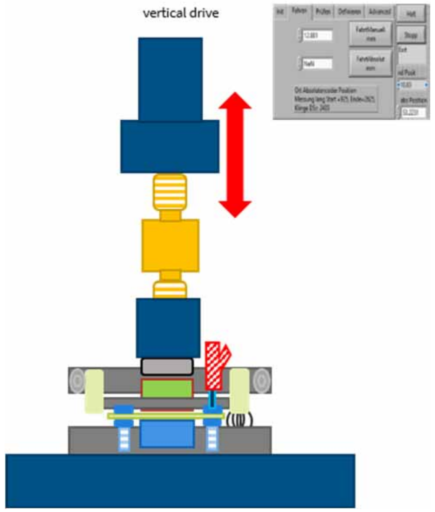
Carsten Kuhn, internal report

The slide deformed almost equally in both directions, at 1000 N approx. 16 - 18 µm.

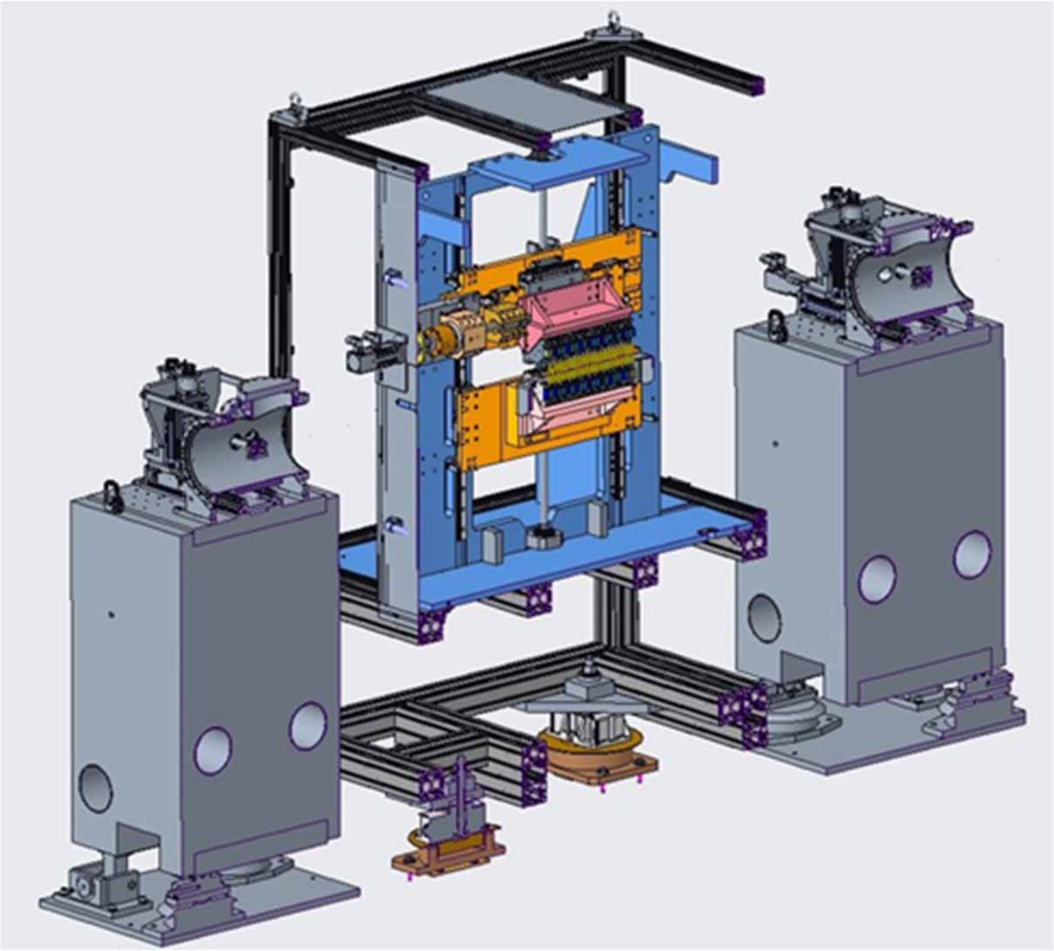
JOINING / MEASURING MULTIPURPOSE TEST STAND



One A- and one B-magnet (horizontal and vertical easy axis orientation) are solderd to a pair.



DEVELOPMENT OF THE IN-VACUUM APPLE II UNDULATOR IVUE32

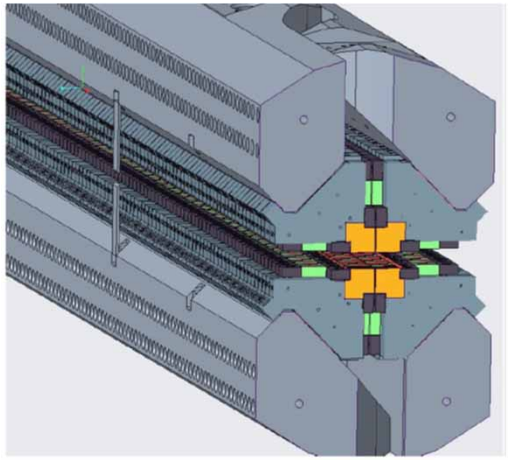


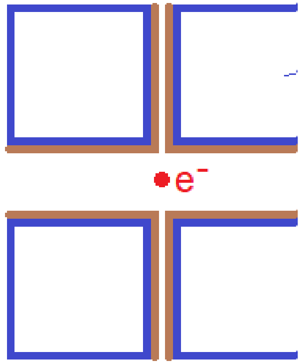
10-PERIOD PROTOTYPE

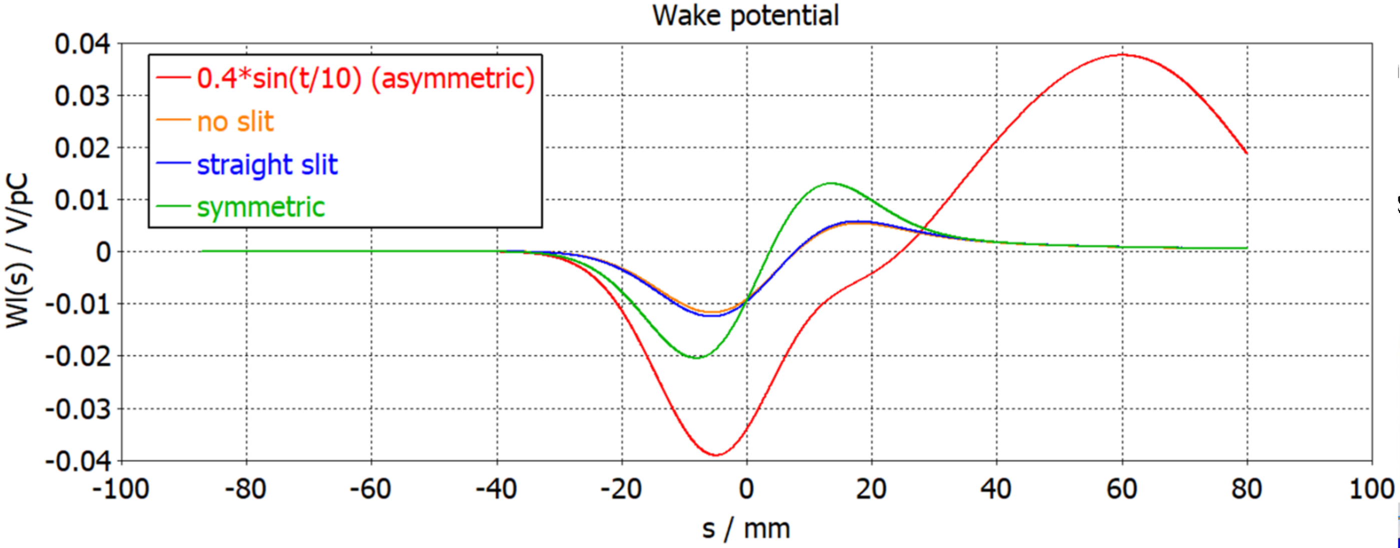
- Magnet pair either soldered or clamped into the keeper.
- Soldering and clamping of the magnets checked with a 10-period lifetime-test setup, applying 800.000 full load cycles to the critical joints.
- Field integrals are measured regularly

DEVELOPMENT OF THE IN-VACUUM APPLE II UNDULATOR IVUE32

Wakefields and Impedances



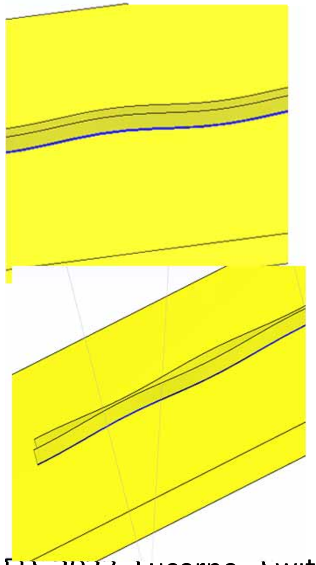


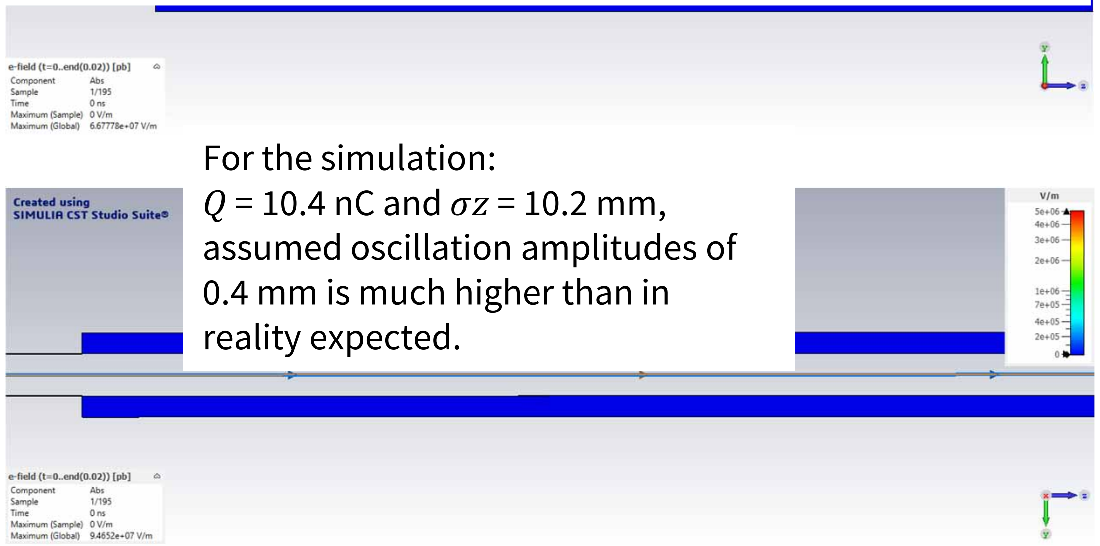


SHIELDING FOIL CONSIDERATIONS

Manufacturer states several possible errors when folding the foil:

- Each side of the slit can develop sinusoidal deformations
- When shifting, geometry of slit could change





For the simulation:
Q = 10.4 nC and σz = 10.2 mm,
assumed oscillation amplitudes of 0.4 mm is much higher than in reality expected.

Simulation: Paul Volz

Loss simulation, Paul Volz in IPAC 2023, Venezia, Italy

DEVELOPMENT OF THE IN-VACUUM APPLE II UNDULATOR IVUE32

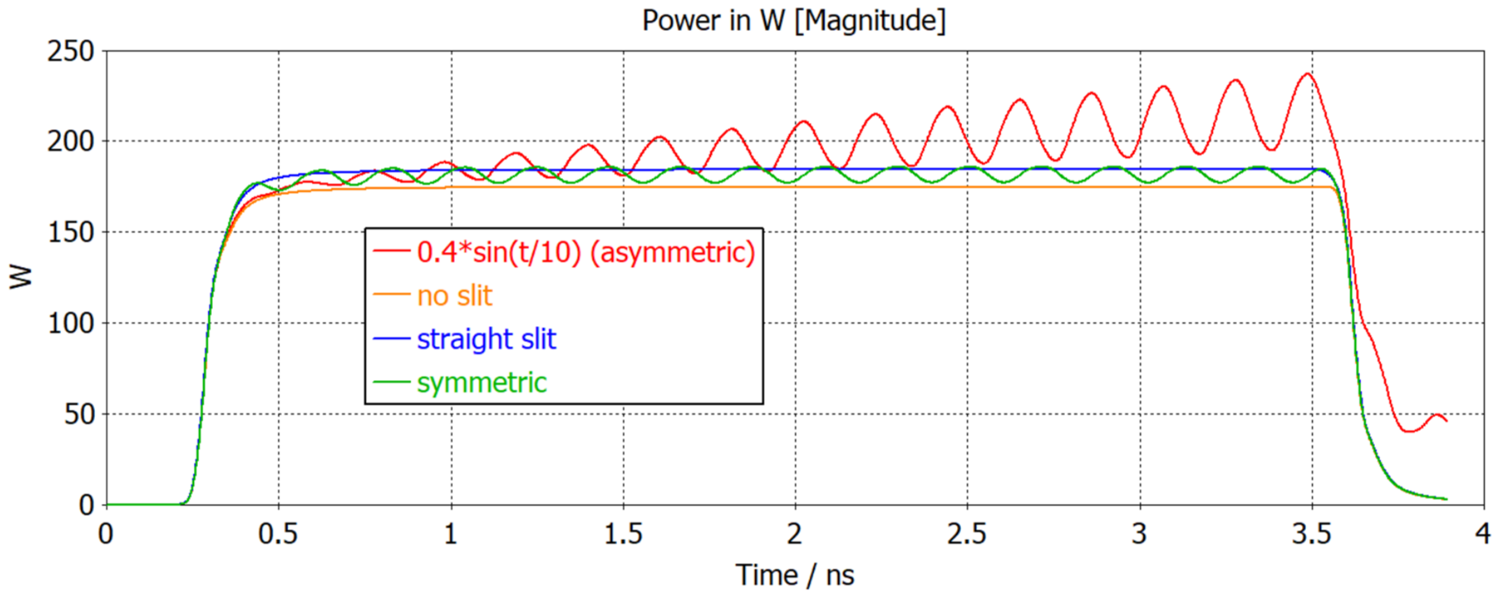
SHIELDING FOIL CONSIDERATIONS

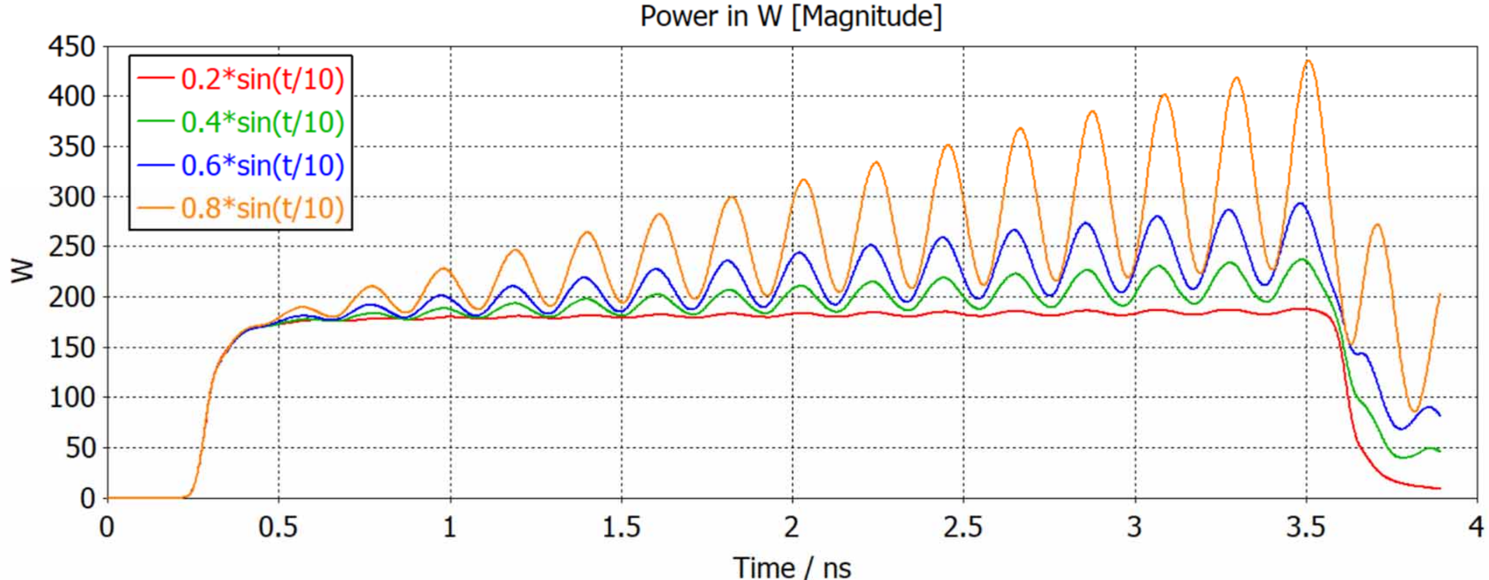
For the simulation:
Q = 10.4 nC and σz = 10.2 mm, 7mm gap, and an assumed oscillation amplitudes of 0.4 mm. The amplitude is much higher than in reality expected.

Even then the total loss power < 10 W for Hybrid fill pattern of BESSY II

- The effects of geometric errors on the losses strongly depend on their amplitude.
- First inquiries to possible foil manufacturers suggest error amplitudes less than 0.2 mm are achievable over a 2 m bend. Perfectly periodic errors are unlikely.
- Conclusion: suitable shielding foils can be manufactured.

Wakefields and Impedances

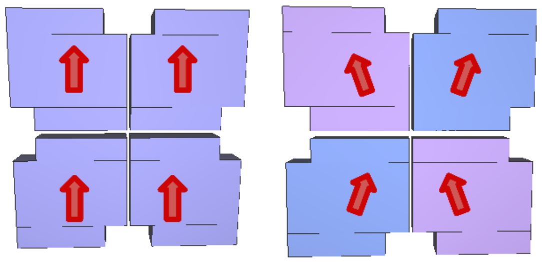


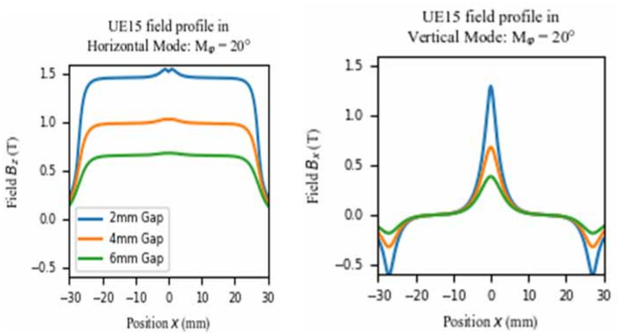


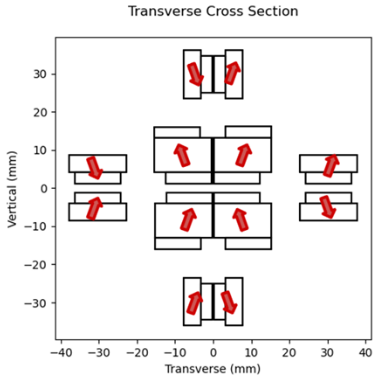
Loss simulation, Paul Volz in IPAC 2023, Venezia, Italy

CRYOGENIC APPLE: MAGNET AND KEEPER DESIGN

Recovering On-Axis Dip at 2mm gap: rotation of Easy Axis by 20°

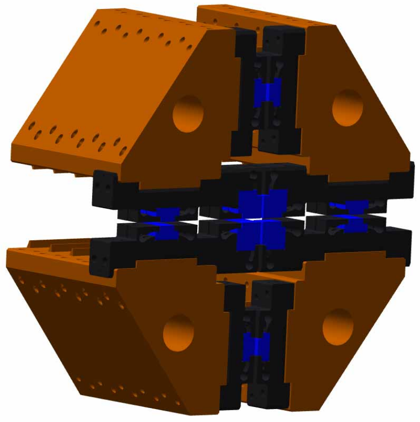




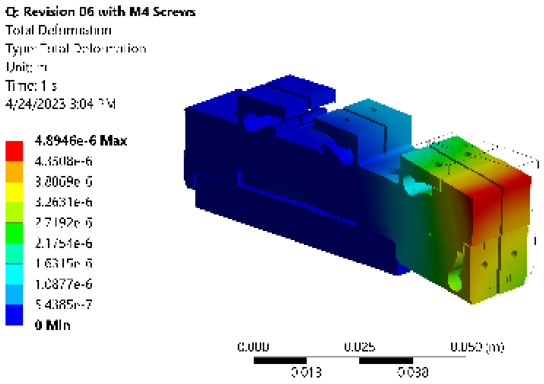


Due to rotation of Easy Axis of the functional magnets, this rotation also needs to carry through to Compensation Magnets

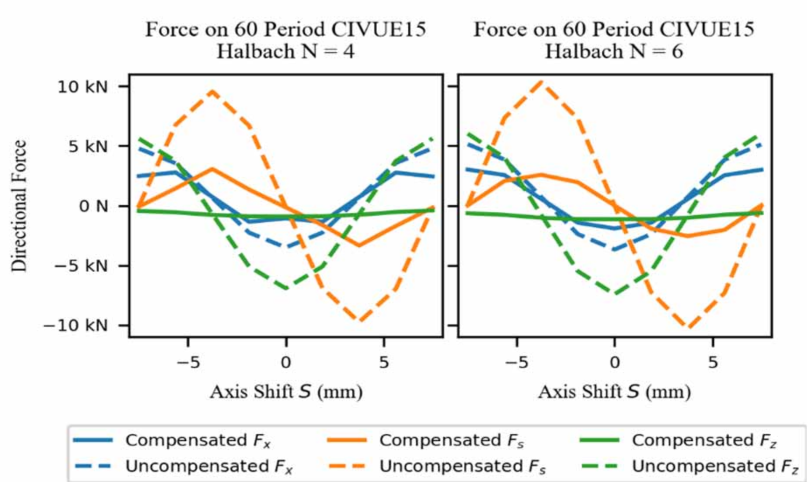
Assembly of primary and secondary keepers on cold magnet girders, in a force compensation arrangement



Finite element analysis of primary keeper of the cryogenic APPLE under 100N of vertical force.



The force on the girder carrying magnet row 1 with and without a magnetic force compensation scheme

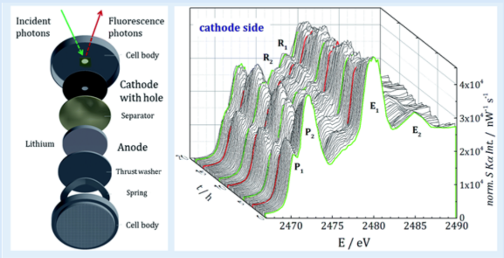


E. Rial in IPAC 2023, Venezia, Italy
E. Rial in LEAPS-INNOV Annual Meeting 2022

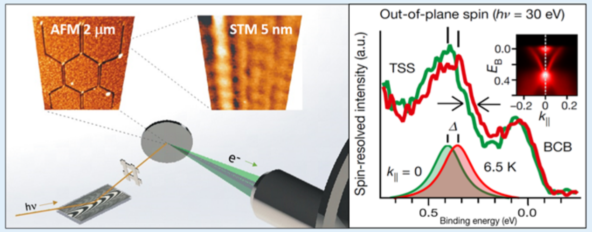
SOFT AND TENDER X-RAY

Requirement

High flux in a wide photon energy range from soft to tender X-rays and a high degree of polarization control (full polarisation control for soft X-rays).



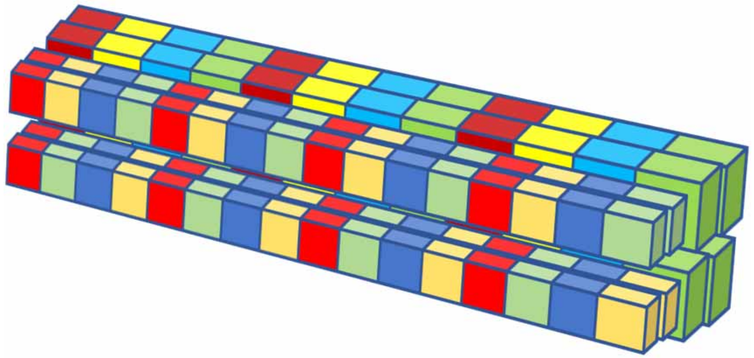
Energy Conversion and Storage

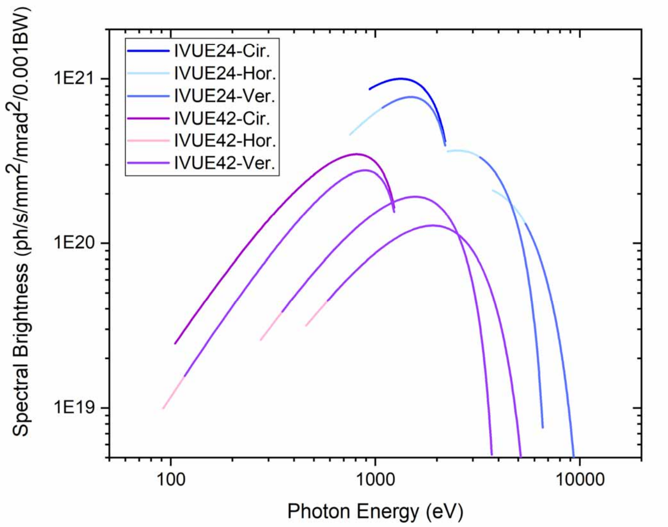


Quantum and Information Technologies

Proposal

Double Period Undulator (DoPU).





Challenges

- Transverse shift of the in-vacuum structures of the order of tens of cm.
- the taper section connecting the accelerator vacuum chamber to the in-vacuum DoPU
- …

Required Technical Developments

- Combined gap and shift motion.
- Detachable flexible tapers.
- In-situ gap and shift measurements.
- In-vacuum magnet field measurements.
- …

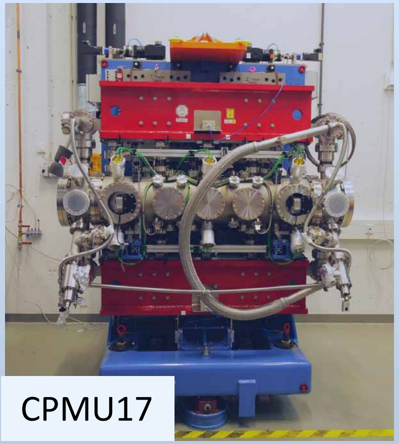
SUMMARY AND OUTLOOK

- IDs are essential for the future BESSY III; they are an indispensable prerequisite for achieving its scientific goals.
- The development work for in-vacuum APPLEs will be continued (Shielding foil in the taper sections, final vacuum chamber design and assembly strategy,…)
- Taking advantage of gained experiences and knowledge with CMPU17, IVUE32 and Cryo IVUE innovative undulator concepts will be utilized for BESSY III

REFERENZES

- J. Bahrdt et al, “Phase-Shimming of the BESSY II in-Vacuum APPLE II Undulator IVUE32 with Transverse Slides”, 2022 , J. Phys.: Conf. Ser. 2380 012014
- E. C. M. Rial et al, “Development of a cryogenic APPLE CPMUE15 at BESSY II” 2022,J. Phys.: Conf. Ser. 2380 012018
- E. C. M. Rial et al, “ UNDULATORS FOR BESSY III” in Proc. IPAC’23, Venezia, Italy
- P. I. Volz, “LOSS SIMULATIONS ON SHIELDING FOIL SLIT ERRORS”, Proc. IPAC’23, Venezia, Italy
- J. Bahrdt et al., “The Status of the In-Vacuum-APPLE II Undulator IVUE32 at HZB / BESSY II”, in Proc. IPAC'22, Bangkok, Thailand
- M. Huck et al, “TRANSVERSE BROAD-BAND IMPEDANCE STUDIES OF THE NEW IN-VACUUM CRYOGENIC UNDULATOR AT BESSY II STORAGE RING”, in Proc. IBIC 2020, Santos, Brazil
- M. Huck et al, “FIRST NUMERICAL WAKEFIELD STUDIES OF NEW IN-VACUUM CRYOGENIC AND APPLE II UNDULATORS FOR BESSY II”, in Proc. IPAC’21, Campinas, SP, Brazil
- M. Huck et al, “EXPERIMENTAL STUDIES OF THE IN-VACUUM-CRYOGENIC UNDULATOR EFFECT ON BEAM INSTABILITIES AT BESSY II”, in Proc. IPAC’21, Campinas, SP, Brazil

BESSYII



BESSY III