Karlsruhe Institute of Technology

Insertion devices and magnet technology

Sara Casalbuoni
KIT IBPT

IBPT Institute for Beam Physics and Technology

Outline

- Status development MT in Germany
- Status development IDs in Germany
- IDs LEAPS proposal*
- Conclusions

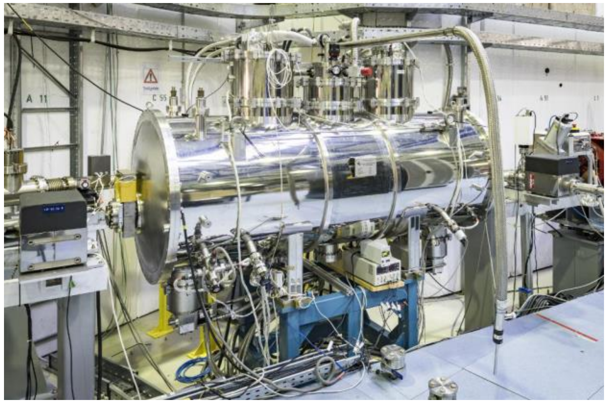
*__Proposal for LEAPS R&D Topic Insertion devices (LIDs)__
Coordinator of R&D Topic: Marie-Emanuelle Couprie (SOLEIL), Thomas Schmidt (PSI)
Contacts: Marie-Emanuelle Couprie (SOLEIL), Thomas Schmidt (PSI), Markus Tischer (DESY), Bruno Diviacco (Elettra), Joël Chavanne (ESRF), Johannes Bahrdt (HZB), Ed Rial (Diamond), Hamed Tarawneh (MaxLab), Josep Campmany (Alba), Sara Casalbuoni (KIT IBPT), Jim Clarke (STFC, Daresbury)

Status development MT in Germany

- **BESSY II, PETRA III, PETRA IV**
  - Non-linear kicker for top-up operation mode to avoid excitations of stored beam at HZB

- **CLIC**
  - NbTi superconducting wiggler for damping rings developed in the collaboration BINP, CERN, KIT LAS, KIT IBPT in operation at KARA

SCW51 @ KARA



- **FAIR**
  - Engineering design finished for all magnets and production started for dipoles GSI + industrial partners

E. Fischer et al, IPAC2017

- **HL- LHC, HE-LHC, FCC Nb_3Sn magnets**
  - Radiation damage tests. Collaboration KIT LAS, CERN

Status development MT in Germany

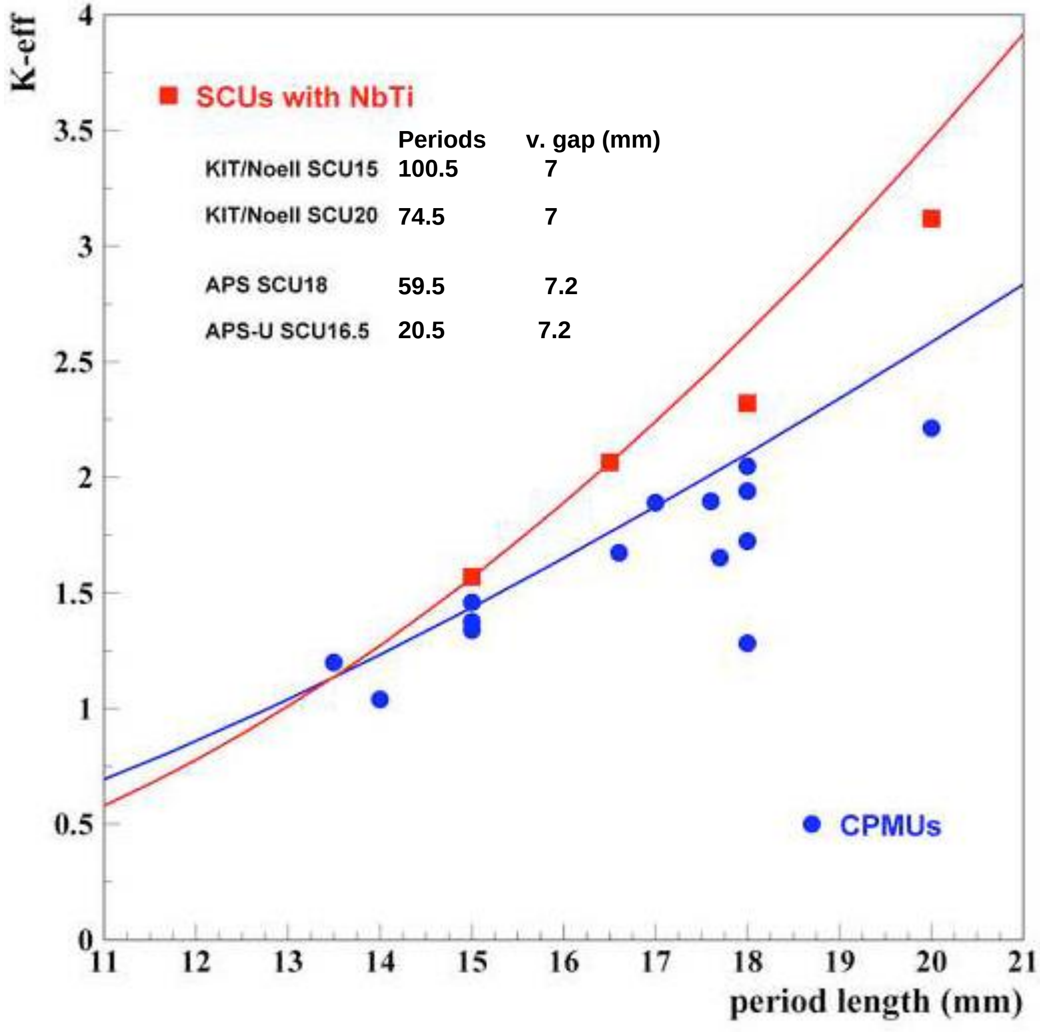
- **CERN “future magnets” initiative roadmap**
  - First successful HTS-Roebel dipole demonstrator qualified the concept and surpassed all technical goals. A very high performance of the HTS magnets may compensate possible limitations of necessary improvements of the Nb_3Sn LTS outsert magnets. Developed innovative quench detection.

    Collaboration KIT ITEP, CERN

Courtesy W. Goldacker

- **Cryogenic safety in experimental particle physics**
  - Experimental testing on cryogenic pressure relief. Collaboration KIT ITEP, CERN. Unique cryogenic safety test facility at KIT ITEP: PICARD.
  - Cryogenic safety procedures in AMICI (Accelerator and Magnet Infrastructure for Cooperation and Innovation). Collaboration KIT ITEP, CEA, CERN

Status development IDs in Germany

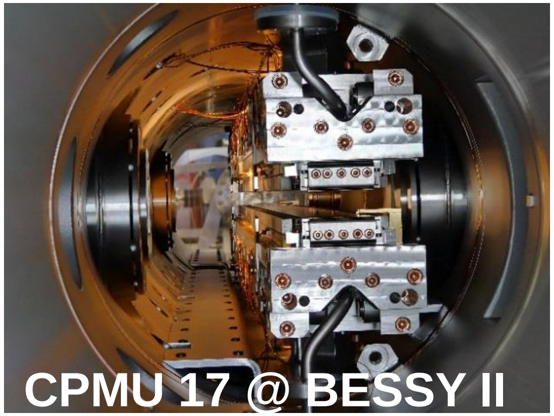


Effective K-values of built CPMUs and SCUs in comparison with theoretical curves

J. Bahrdt and E. Gluskin
https://doi.org/10.1016/j.nima.2018.03.069

Status development IDs in Germany

- **Cryogenic permanent magnet undulators (CPMU)**
  - In construction CPMU17 (HZB) for BESSY II, CPMU15 (HZB, Uni Hamburg and DESY) for laser plasma driven free-electron laser, two CPMU9 for table top FEL built (HZB), one tested with beam at MAMI
- **In vacuum test bench developed at HZB**



Courtesy J. Bahrdt

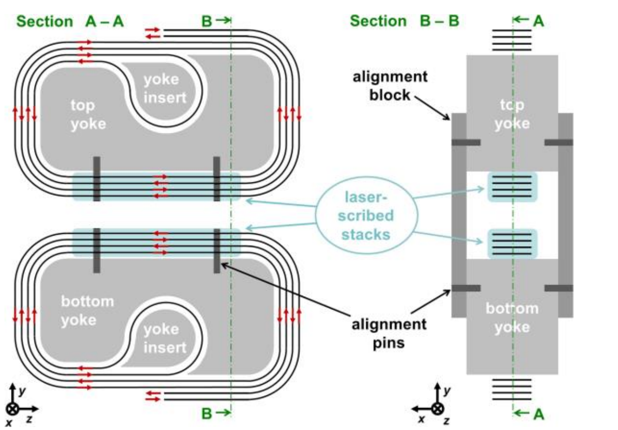
- **NbTi superconducting undulators (SCU)**
  - SCU15 successfully tested in KARA

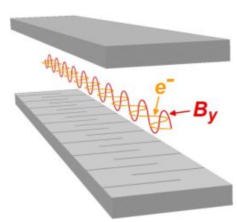
    (KIT IBPT, Bilfinger Noell GmbH)
  - In operation at KARA first commercially available SCU20 (KIT IBPT, Bilfinger Noell GmbH)
  - In construction for a laser wakefield accelerator TGU10.5 (KIT LAS, Uni. Jena)
- **CASPER II horizontal conduction cooled test facility developed at KIT IBPT**

Status development IDs in Germany

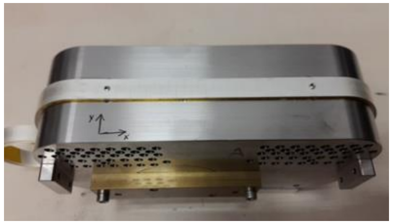
- **Switchable period length: aim is to reach high brilliance and tunability with longer period and high brilliance with first harmonic of longer period down to few tens of eV (i.e. 50 eV for all M-edge absorption of Fe)**
  - In operation in KARA in vacuum switchable period length from 28 mm to 50 mm: two magnetic structures horizontally shifting (KIT IPS, KIT IBPT, Danfysik)
  - NbTi SCU mockup developed, built and tested at KIT IBPT with period length doubling from 17 mm to 34 mm (BMBF financed) Bundesministerium für Bildung und Forschung

- **Jointless HTS tape stacked undulator**
  - Proposed for table top FEL at KIT IBPT, KIT ITEP





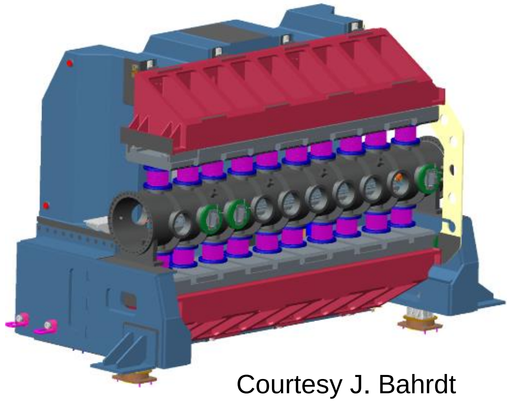
Period length = 8 mm
m. gap = 2.5 mm
w =12 mm B = 1.0 T
w > 20 mm B = 1.4 T



T. Holubek et al., Supercond. Sci. Technol. 30 115002 (2017)

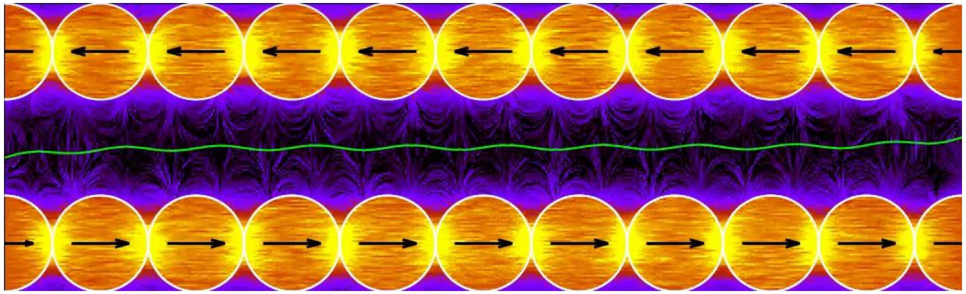
Status development IDs in Germany

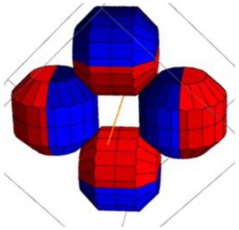
- **APPLE II to produce elliptically polarized photon beams for low emittance synchrotrons (elliptical vacuum chamber)**
  - In operation at BESSY II (HZB) and PETRA III (HZB and DESY)



Courtesy J. Bahrdt

- **In vacuum APPLE II**
  - Under development at HBZ for BESSY II
- **Variable period helical undulator with tunable polarization**
  - Proposed by DESY for FELs and diffraction limited storage rings





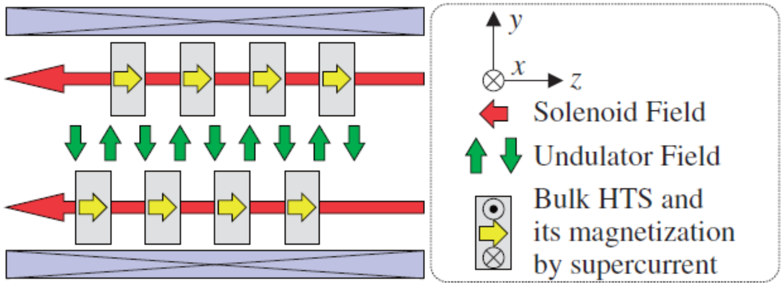
P. Vagin, ID Workshop, Berkeley, 2017

IDs LEAPS proposal

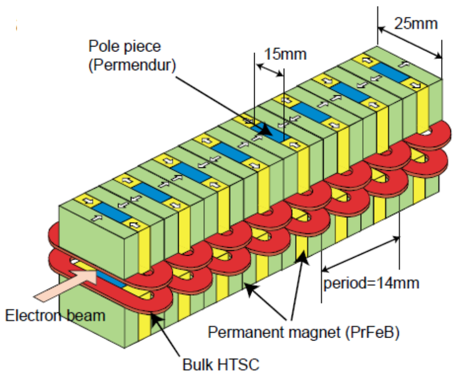
LEAPS - the League of European Accelerator-based Photon Sources

- **Short period, high field undulators will be developed pursuing three different technological approaches:**
  - furthering the concept of the CPMU (new magnet grades, longer und., operation < 77K, use of additional superconducting coils)
  - improved planar SCUs (LTS, HTS and switchable period length)
  - persistently magnetized bulk high temperature superconductors (HTS)

bulk HTS staggered array undulator (BHSAU)



R. Kinjo et al, Appl. Phys. Express **6** 042701 (2013)



T. Tanaka et al., PRSTAB **7** 09704 (2004)

IDs LEAPS proposal

LEAPS - the League of European Accelerator-based Photon Sources

- **Advanced EPUs will be developed, with the aim of simplifying the design and reducing the cost of these devices, and to make available advanced use cases to users. New schemes could also be considered, perhaps including superconducting technology similar to the superconducting arbitrary polarization emitter (SCAPE) device under consideration at Argonne**

- **Improved room temperature permanent magnet undulators, such as transverse gradient undulators of interest to laser plasma accelerator based FELs, or revised revolver undulators (for round beams) will be developed**

- **The corresponding development of measurement benches will be needed for the prototype devices, with a new generation of measurement systems able to measure within the confines of narrow gap, cold, UHV compatible environments**

Conclusions

Personal view

- **x years period**
  - **Non-linear kicker magnets + measurement system** O. Dressler, TWISS Workshop, Berlin 2017
  - **Short pulse kickers for swap-out injection ⟹ fast electronics** F. Obier and R. Wanzenberg, private communication
  - **Septa: less stray fields and smaller separation**
- **10 years period**
  - **HTS tape magnets for future circular collider**

Conclusions

Personal view

- **Most of LEAPS proposal points for a period of 10 years**

- **LEAPS proposal 3 years development**
  - **studies on prototypes of persistently magnetized HTS bulk**
  - **switchable period length NbTi SCU**

- **3 years period**
  - **THzSCUs: the larger aperture for the same peak field and period length with respect to PM technology, helps a better transmission of THz radiation. Enhanced coherent (synchrotron, transition, diffraction) radiation from short bunches, i.e. FLUTE, XFEL** (see talk M. Gensch)

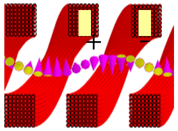
Conclusions

Personal view

- **10 years period**
  - **Circularly polarized SCU SASE line for XFELs?**

Aim: reduce the gain length of 20-30%

or to lower the beam energy



D J Scott et al, Phys Rev Lett, 107, 174803 (2011)

J. Fuerst et al, FLS18 Workshop, Shanghai, 2018

Installed at APS
31.5 mm period
m. gap 29 mm
v. gap 26 mm (h) x 8 mm (v)
B_{max}=0.42 T
K_x=K_y=1.2

- **3 years period**
  - **In vacuum SCU for FELs?**

Aim: further increase the magnetic peak field on axis

In vacuum Nb Ti SCU prototype
15.5 mm period
7.4 mm gap
B_{max} = 1.25 T
K_{max} = 1.8
Soon to be installed and tested on the CLARA FEL Test Facility at Daresbury

Courtesy J. Clarke

Conclusions

Additional points (A.-S. Müller)

- **Standardization of power supply/controls**
- **Modularity power supplies**

Thanks to

- Johannes Bahrdt (HZB)
- Markus Tischer, Pawel Vagin (DESY)

- You for your attention!

Backup slides

Multipole Kicker Magnets - Limitations by Accelerator

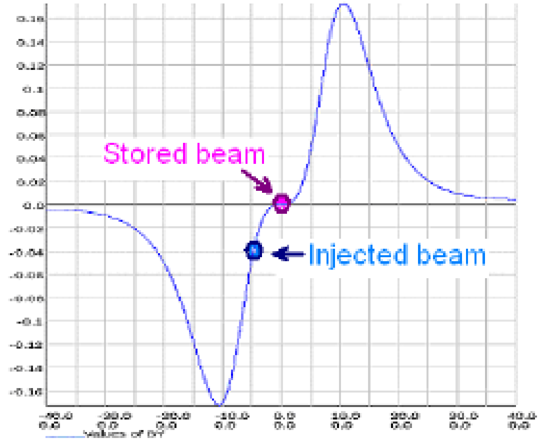
Multipole Injection Kicker (MIK) development at SOLEIL for MAX VI is succeeding BESSY NL-Kicker design.

Advantages of MIK Concept:

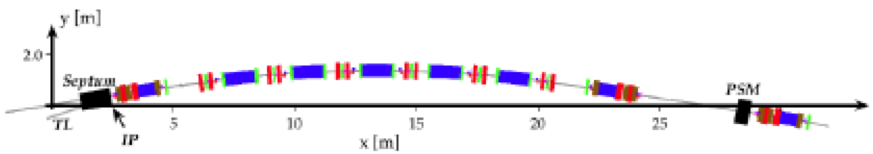
- *Non-disturbed* stored beam in top-up injection mode.
- *Octupole* like field distribution with zero field on axis and flat B_y-field maximum at a certain distance. Only injected beam deflected.

Limitations of MIK Concept:

- *Positioning* of the MIK within the storage ring by considering non-linear optics of modern accelerators. Changes in optics may require to move kicker.
- *Vertical aperture* requirements limit positioning of the kicker coils; injected beam at chosen position may not be at B_y-field maximum of non-linear field distribution.
- Limitation for the *excitation pulse length* by revolution time; injected beam only kicked once.
- *Small emittance* of injected beam required.



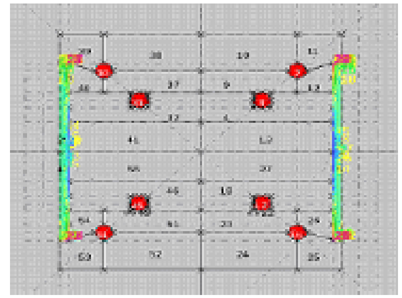
Reference:
S.C. Leemann, Phys. Rev. ST Accel. Beams 15, 050705, 'Pulsed sextupole injection for Sweden's new light source' MAX IV, 2012.



Multipole Kicker Magnets - Technological Challenges

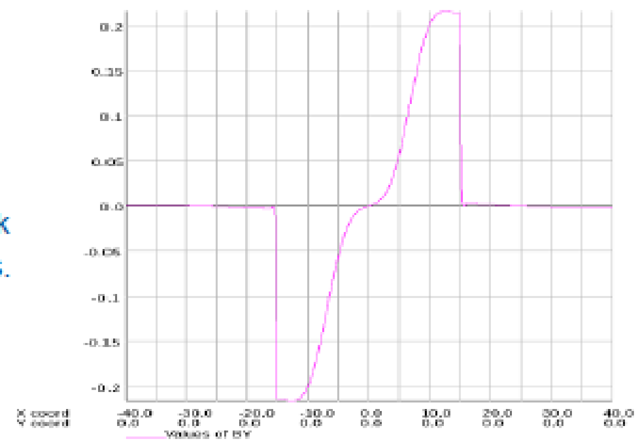
Technological Challenges of MIK Concept:

- Precise wire positioning in alumina (1/100 mm).
- Sensitive vacuum system with welded flanges to ceramics.
- Uniform coating of alumina with Titanium for mirror current path and good rf containment.
- Low inductance pulse power circuit for required high pulse currents at short pulse duration.



Technical details:

- Eddy currents in neighboring metallic surfaces cause field distortion, asymmetries and weakening.
- Proper contacting of coated surface to avoid rf power loss and temperature rise of component.
- Pulsed PS outside the tunnel foreseen, to avoid risk of radiation damage on switching power electronics.
- Now long cables are necessary with 'pseudo matching' to keep load impedance low.



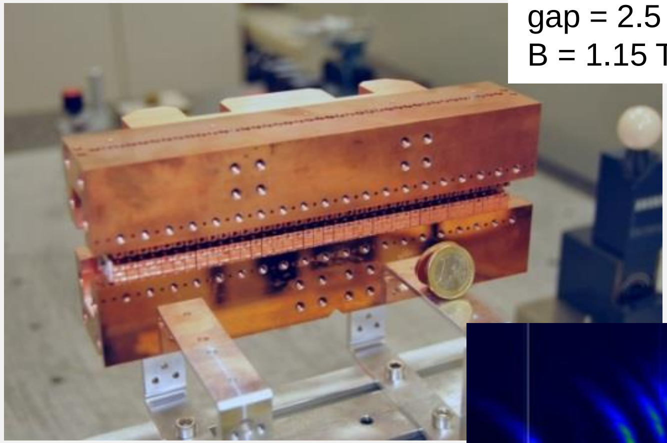
Reference:
P. Lebasque, Magnetic and electric evaluation in transient mode of the Bessy-II MIK design … (collaboration report), March 2013.

Prototyping Short Period Undulators at HZB

Karlsruhe Institute of Technology

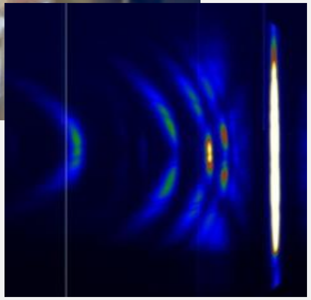
1st 9mm period prototype

- Test of new magnet grade (PrNd)FeB
- Evaluate new mechanics concept
- Operate IV-HP-bench prototype



gap = 2.5 mm
B = 1.15 T

Halbach II undulator
with straight pole

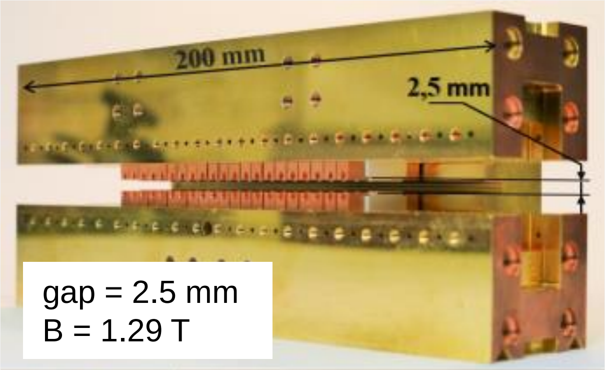


First light @ MAMI

F. Holy et al., Physical Review ST-AB, 17 (2014), 050704.
F. H. O'Shea et al., Phys. Rev. ST-AB, 13 (2010), 070702.

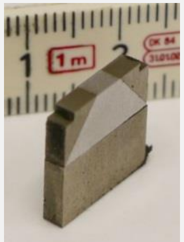
2nd 9mm period prototype

- Explore the field limits
- Side magnets
- New magnet soldering technique



gap = 2.5 mm
B = 1.29 T

Hybrid pole



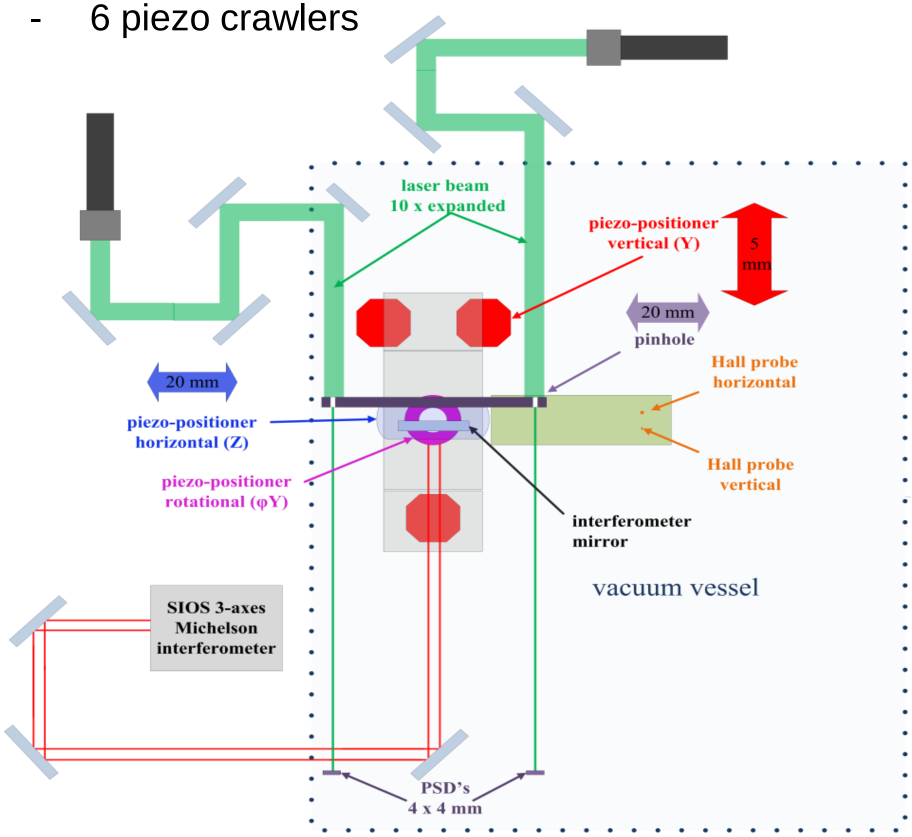
J. Bahrdt, C. Kuhn, Synch. Rad. News, 28, 3 (2015) 9-14.
C. Kuhn, PhD-Thesis, TU Berlin., 2016.

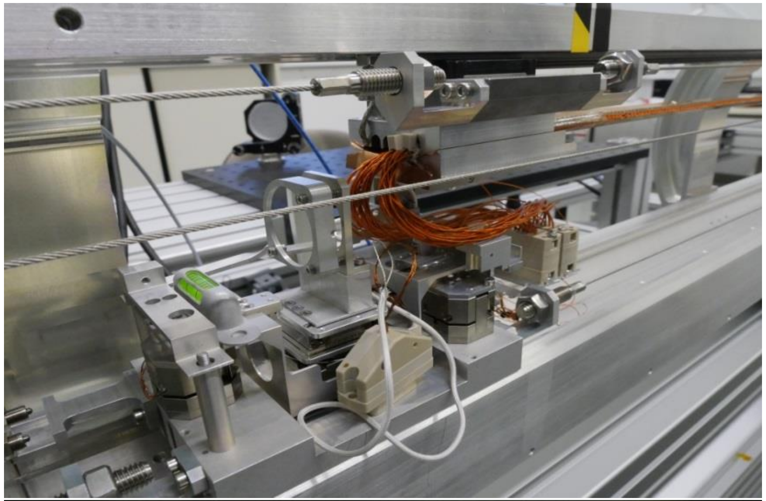
Courtesy J. Bahrdt

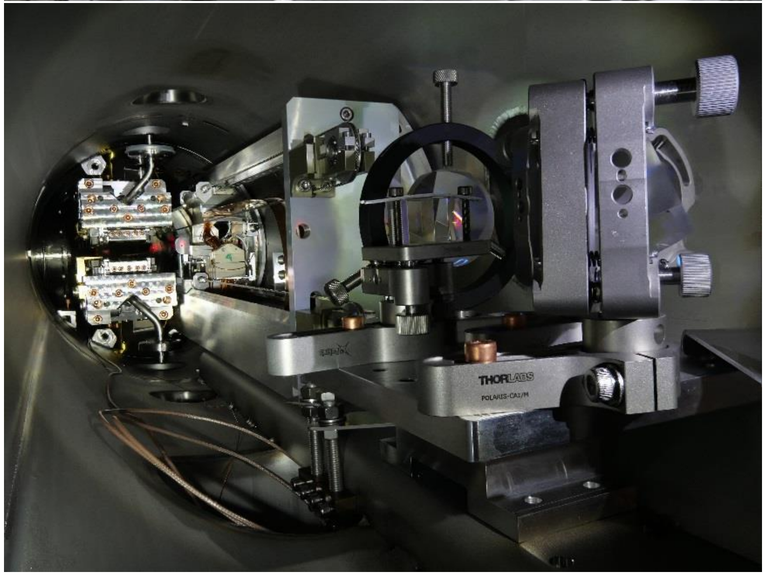
In-Vacuum Hallprobe Bench @ HZB

5 parallel position / angle feedback loops

- 3-axis laser interferometer
- 2 x 2-dim. Position sensitive detector
- 6 piezo crawlers

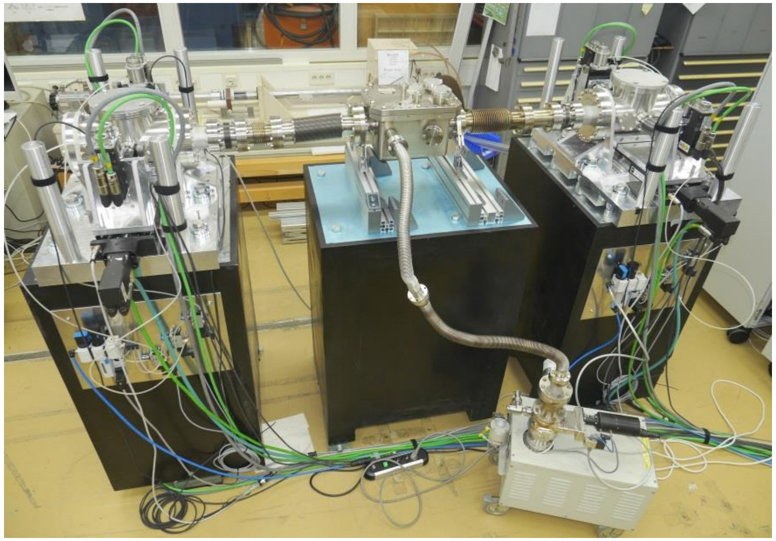






Courtesy J. Bahrdt

New Tools II: In-Vacuum Moving Wire



	$\int B_y \cdot dx$	$\int B_z \cdot dx$
In air	1.6 Tμm	2.3 Tμm
In vacuum 1)	2.9 Tμm	5.0 Tμm
In vacuum 2)	4.2 Tμm	8.7 Tμm

1) 2mm steps, 200ms, 1s delay
2) 1mm steps, 100ms, 1s delay

J. Bahrdt et al., IPAC Busan, South Korea (2016) 1428-1430.

New in-vacuum moving wire
- Motors, bearings outside vacuum
- Automated reference procedure
- Wire tension monitoring

measurement accuracy
defined by wire vibrations

↓

errorr scales

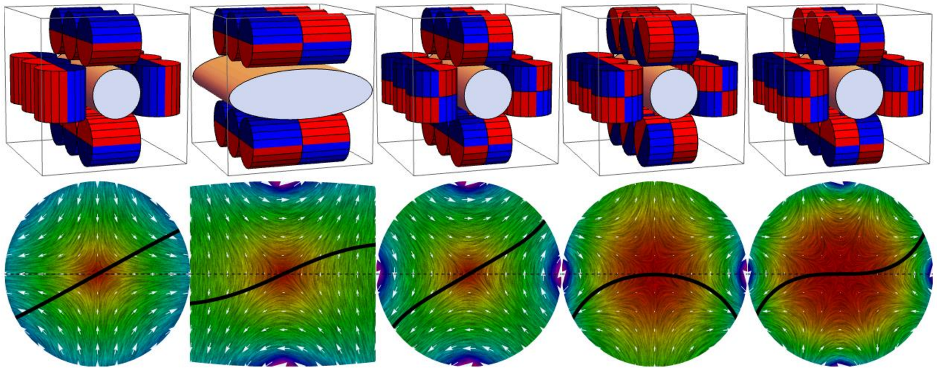
- inversely with step size
- linearly with residuals;
  even smaller errors
  expected for shimmed ID

Precision is well suited for short period in-vacuum and cryogenic undulators

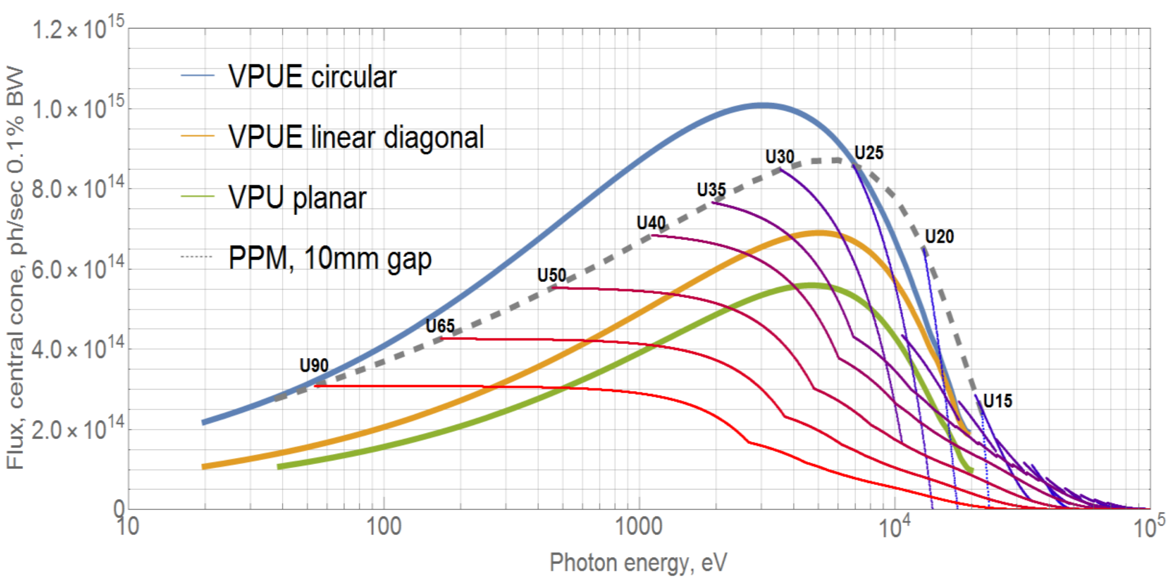
Courtesy J. Bahrdt

Variable period undulators, DESY

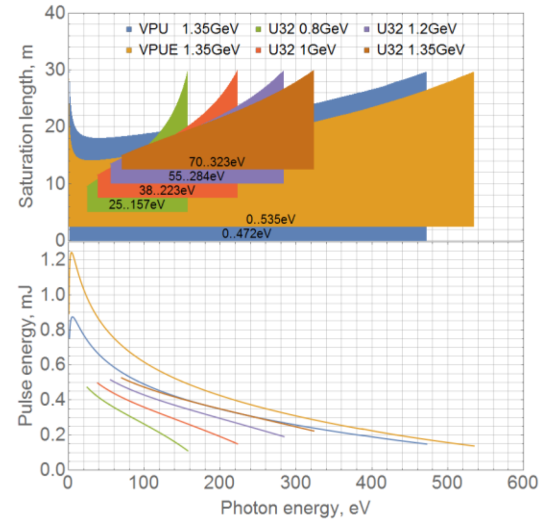
- Helical, tunable polarization
- Higher average flux
- Wider wavelength range
- Embedded magnetic elements, like phase shifters, dipoles, multipoles, …



SRN-2018 Vol. 31-3, xx



Spontaneous radiation, PPM vs VPU, PETRAIII



FEL SASE, FLASH

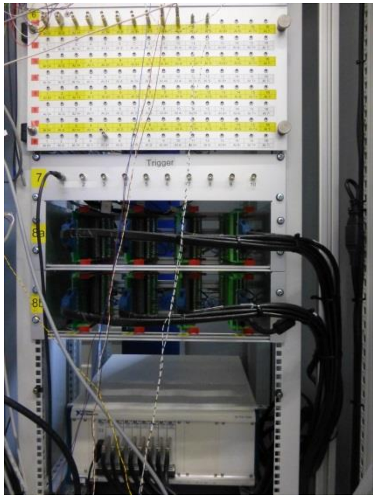
Courtesy M. Tischer

Tools and instruments for R&D: CASPER II

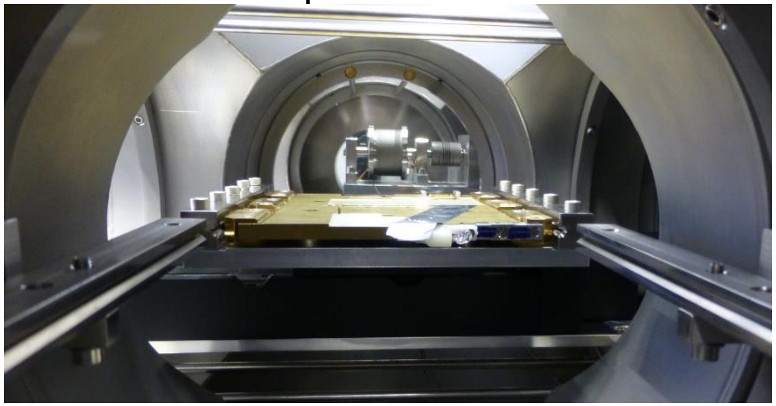
Horizontal cryogen free test stand to characterize conduction cooled undulator coils.

A. Grau et al., IEEE Trans. on Appl. Supercond. 2312-2315 Vol. 21-3 (2011)

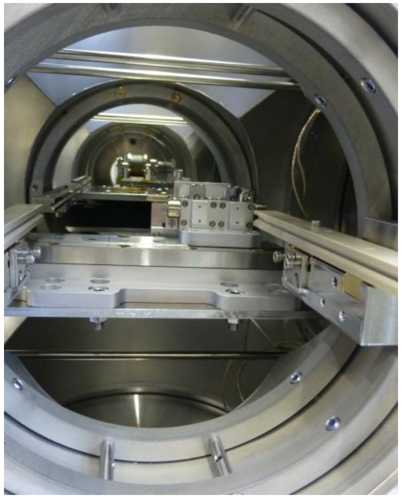
Training:
- Quench detection
- Quench analysis



Local field measurement:
- Hall probes



Integral field measurement:
- Stretched wire



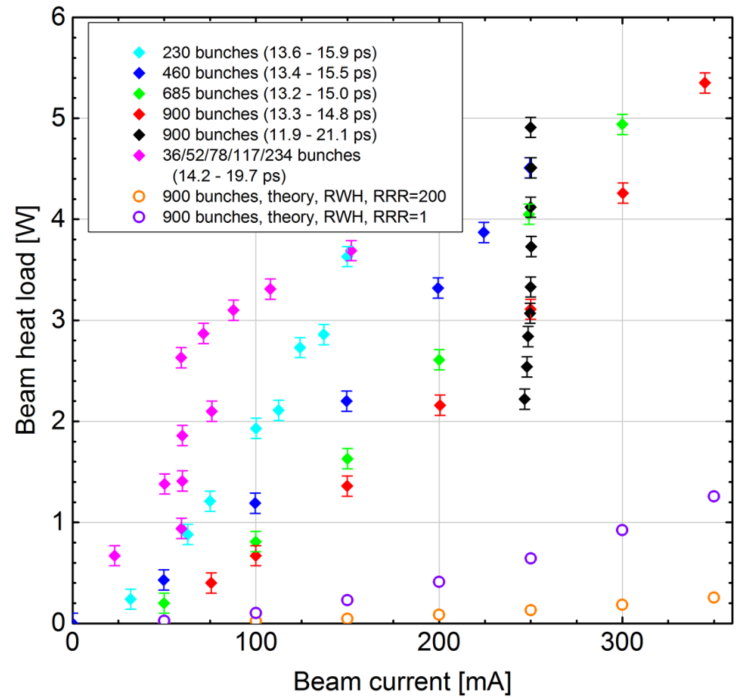
Tools and instruments for R&D: COLDDIAG

Cold vacuum chamber for diagnostics to **measure the beam heat load** to a cold bore in different synchrotron light sources

The beam heat load is needed to specify the cooling power for the cryodesign of superconducting insertion devices

The **diagnostics** includes measurements of the:

- **heat load**
- **pressure**
- **gas composition**
- **electron flux of the electrons bombarding the wall**



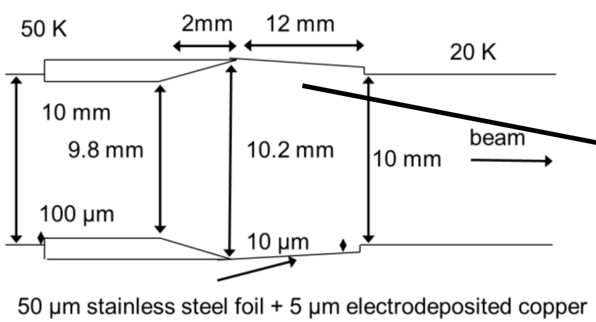
Significant discrepancy compared to theoretical expectations …

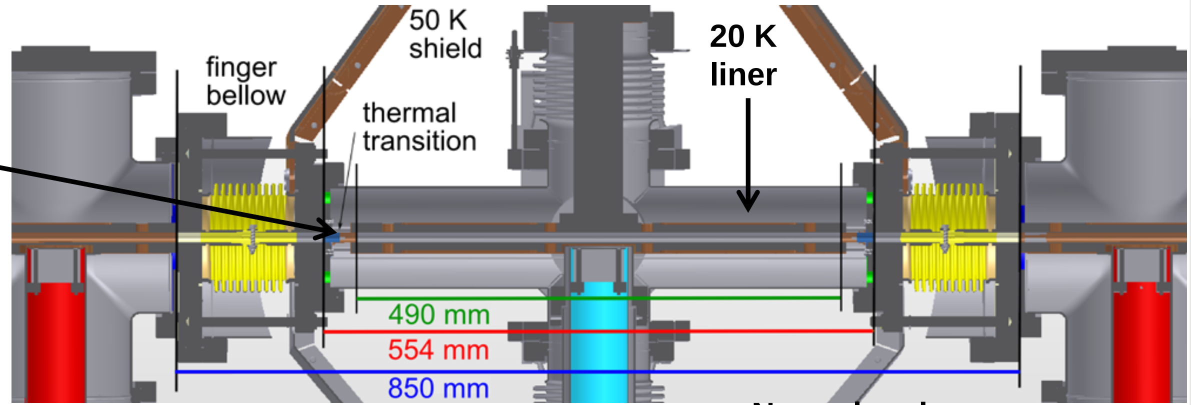
S. C. et al., JINST 7 P11008 (2012)

In collaboration with
CERN: V. Baglin
LNF: R. Cimino, B. Spataro
University of Rome ‚La sapienza': M. Migliorati
DLS: R. Bartolini, M. Cox, E. Longhi, G. Rehm, J. Schouten, R. Walker
MAXLAB : Erik Wallèn
STFC/DL/ASTeC: J. Clarke
STFC/RAL: T. Bradshaw

S. Gerstl et al., PRSTAB, 17, 103201 (2014)
R. Voutta et al., PRSTAB, 19, 053201 (2016)

Tools and instruments for R&D: COLDDIAG



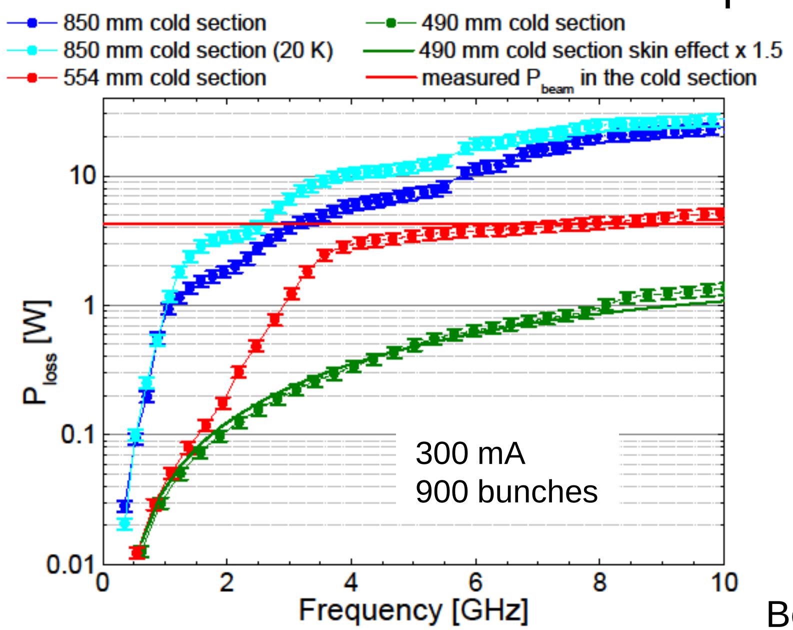


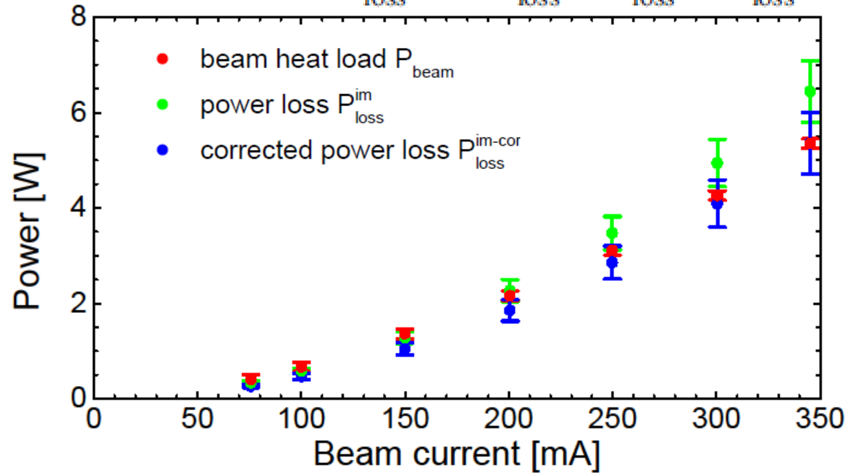
Thermal transitions:
heat from higher temperature regions + imperfections in the geometry.

Impedance bench measurements

Normal and anomalous skin effect

$$P_{\mathrm{loss}}^{\mathrm{im\text{-}cor}} = P_{\mathrm{loss}}^{\mathrm{im}} - P_{\mathrm{loss}}^{\mathrm{sk}} + P_{\mathrm{loss}}^{\mathrm{an}}$$





R. Voutta et al., PRSTAB, 19, 053201 (2016)

Beam heat load observed understood: due to thermal transitions.
Changes in cross section have to be moved between 50 K and RT.