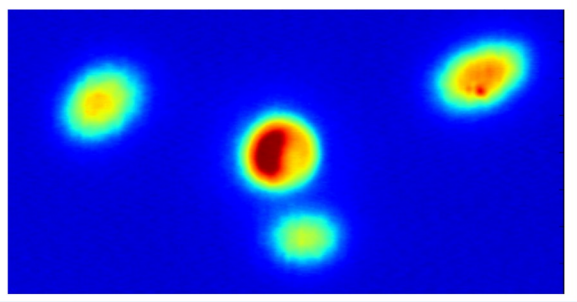
Fast MHz Helicity flipping at BESSY

Alternating the Helicity of X-Ray Photons from an Undulator at Unprecedented Speed

with TRIBs

P. Goslawski et al.
Institute for Accelerator Physics
Helmholtz-Zentrum Berlin



23/24th September 2020
ARD ST3 Meeting 2020, Online in Karlsruhe, Germany

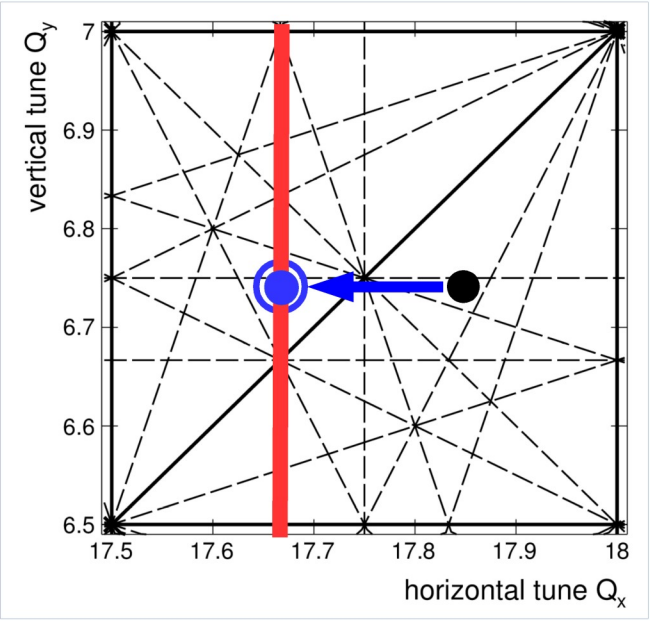
Overview

- TRIBs
  - Summary/History up to now
- MHz Helicity Flipping at BESSY II
  - For XMCD experiments (e.g., PEEM)
- Summary and Conclusions

TRIBs – Working point “on” resonance

Transverse Resonance Island Buckets - **TRIBs** - at BESSY II

- Operating machine close to horizontal 3rd order resonance
- Tackle non-linear beam dynamics
- Minor impact on linear beam optics expected

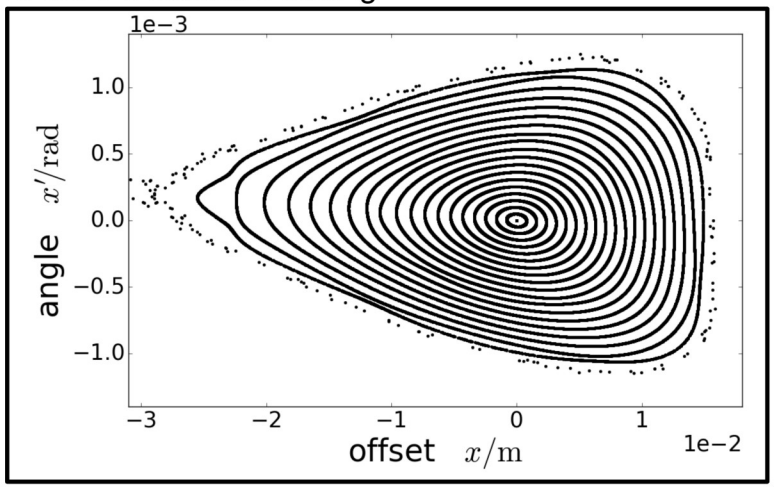


BESSY II working point (17.85, 6.73)

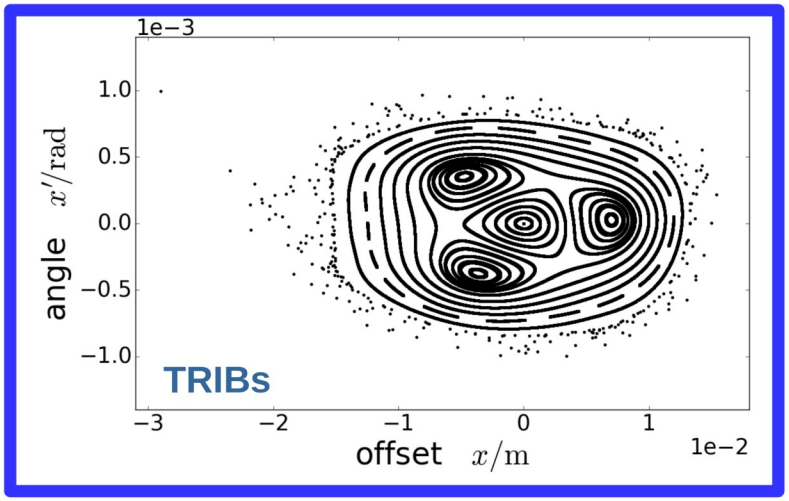
BESSY II TRIBs at 3rd order (17.66, 6.73)

2nd stable fix point & orbit

BESSY II standard setting

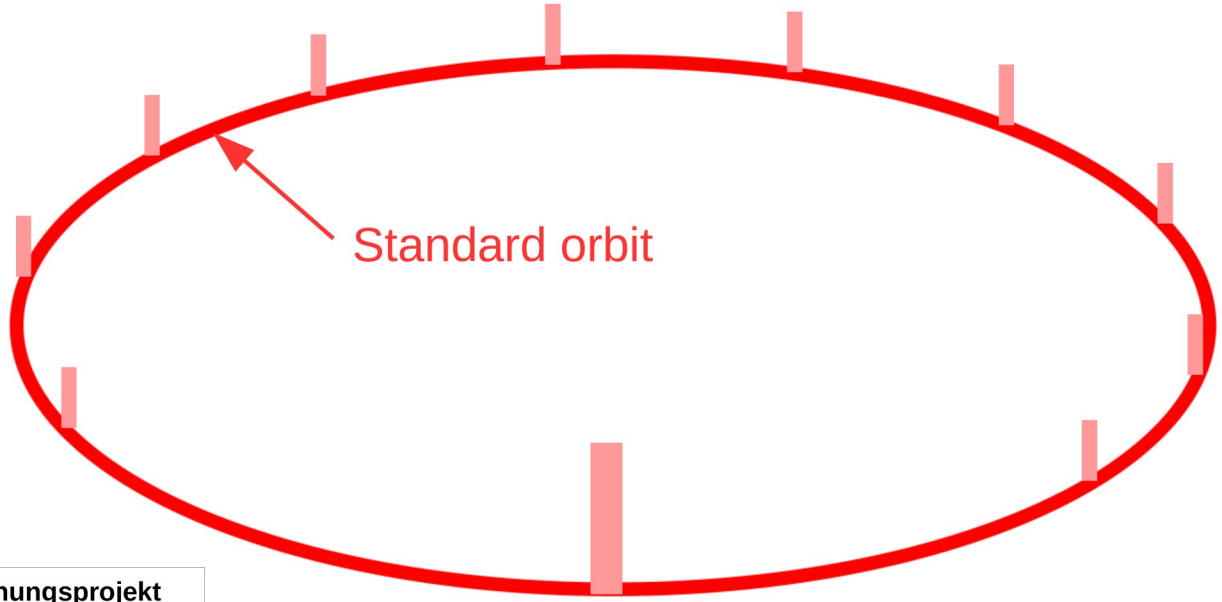


BESSY II TRIBs at 3rd order resonance



Application: A new electron bunch separation scheme

2nd stable orbit with **T**ransverse **R**esonance **I**sland **B**uckets - **TRIBs**



Common Verbundforschungsprojekt

Bundesministerium für Bildung und Forschung

2016-2019
PhD student: TRIBs
as separation scheme

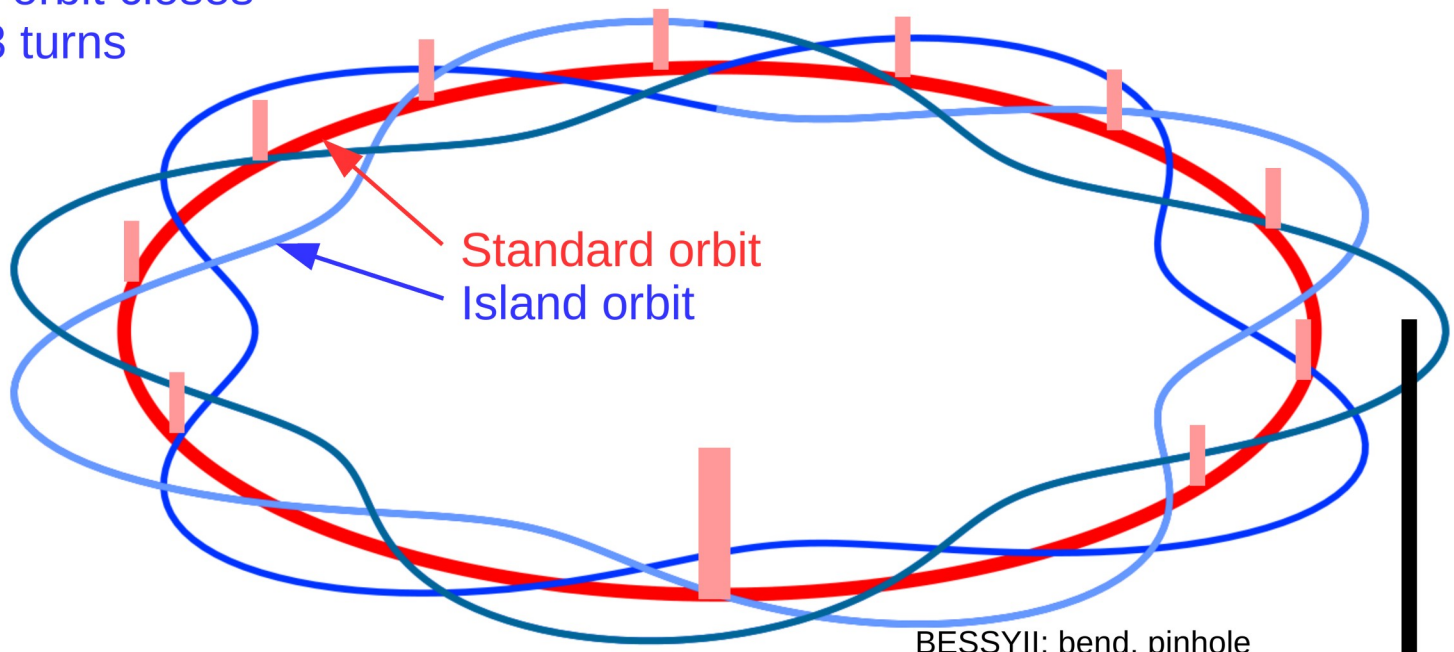
2019-2022
PhD student:
- TRIBs and TopUp injection
- TRIBs for advanced lightsources

Stable 2nd closed orbit for bunch separation
Aim: Multiple beam storage with island buckets

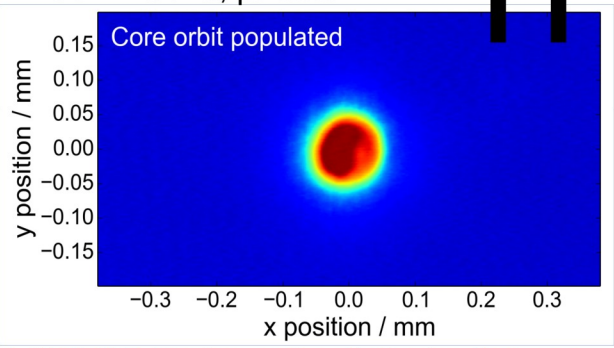
Application: A new electron bunch separation scheme

2nd stable orbit with **T**ransverse **R**esonance **I**sland **B**uckets - **TRIBs**

3rd order resonance
Island orbit closes
after 3 turns



BESSYII: bend, pinhole

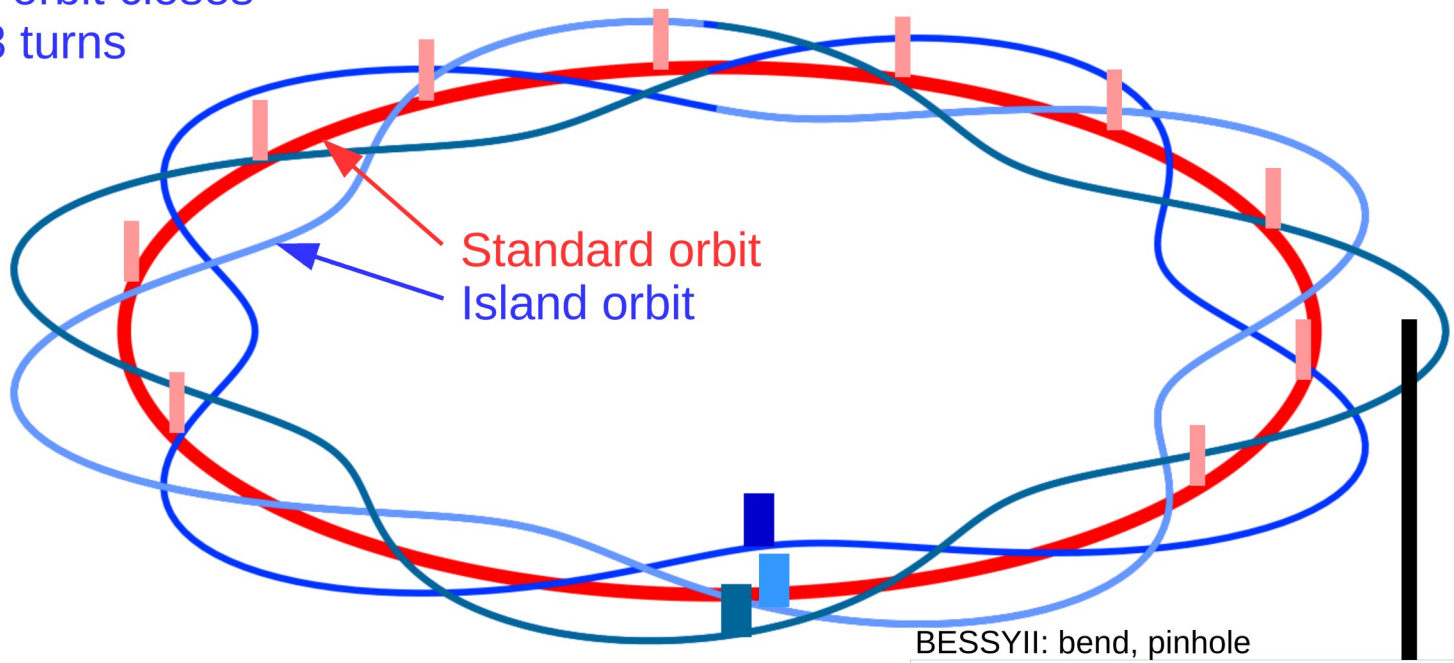


Two stable independent orbits
capable to store
two independent fill pattern

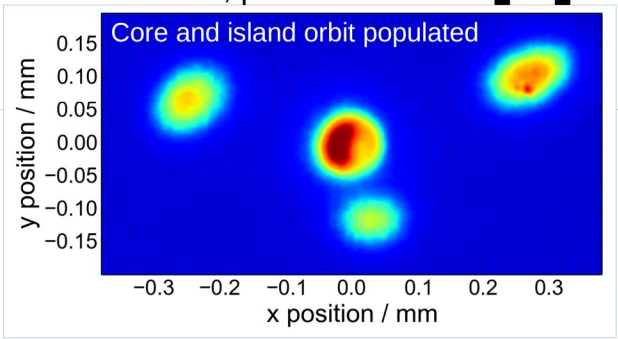
Application: A new electron bunch separation scheme

2nd stable orbit with **T**ransverse **R**esonance **I**sland **B**uckets - **TRIBs**

3rd order resonance
Island orbit closes
after 3 turns

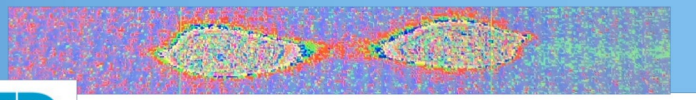


BESSYII: bend, pinhole



Two stable independent orbits
capable to store
two independent fill pattern

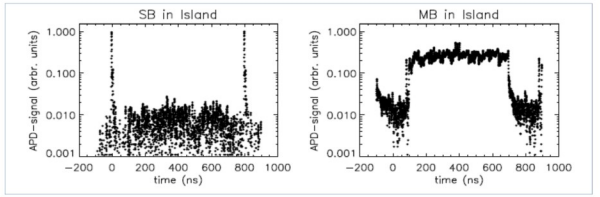
HZB TRIBs Summary/History



2015

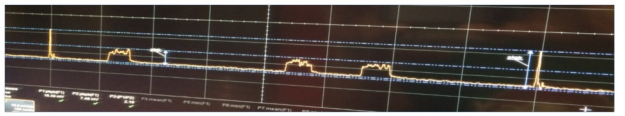
- 1st TRIBs machine exp at MLS
- Followed by first tests at BESSY II

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin



2016

- High current operation at BESSY II, closed IDs
- 1st commen exp. with beamline scientist
- Radiation from 2 orbits usable?



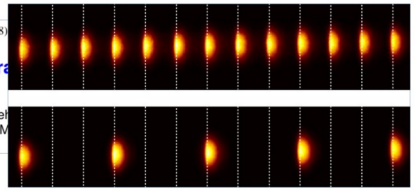
2017

- First TRIBs user experiment at MLS
- Single island population
- to extend the repetition rate

REVIEW OF SCIENTIFIC INSTRUMENTS 89, 103114 (2018)

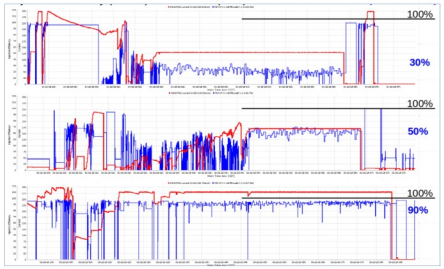
Transverse resonance island buckets for synchrotron-ra
electron time-of-flight spectroscopy

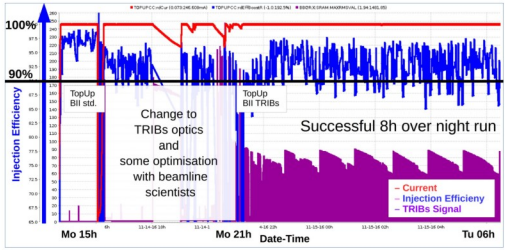
T. Arion,[1] W. Eberhardt,[1,2] J. Feikes,[3] A. Gottwald,[4] P. Goslawski,[3] A. Hoe
M. Kolbe,[4] J. Li,[3] C. Lupulescu,[2] M. Richter,[4,a)] M. Ries,[3,b)] F. Roth,[5,c)] M
T. Tydecks,[3] and G. Wüstefeld[3]



2018

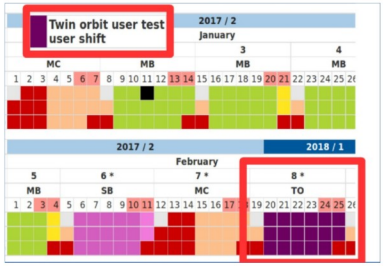
- TopUp injection into TRIBs setting
- at BESSY II @ high current

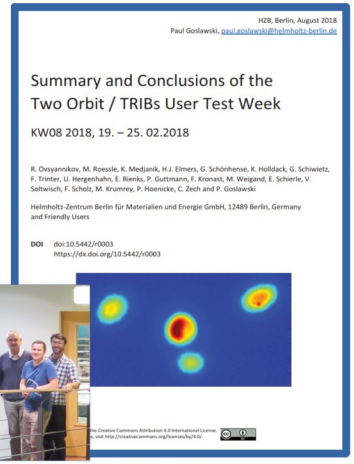




2019

- TwoOrbit / TRIBs User Test Week
- 3 days of exp, 4 days user run





XMCD@TRIBs
BESSY II exp

TRIBs at other Rings
DELTA & MAX IV

- TRIBs workshop at HZB / BESSY II
- Accelerator scientists

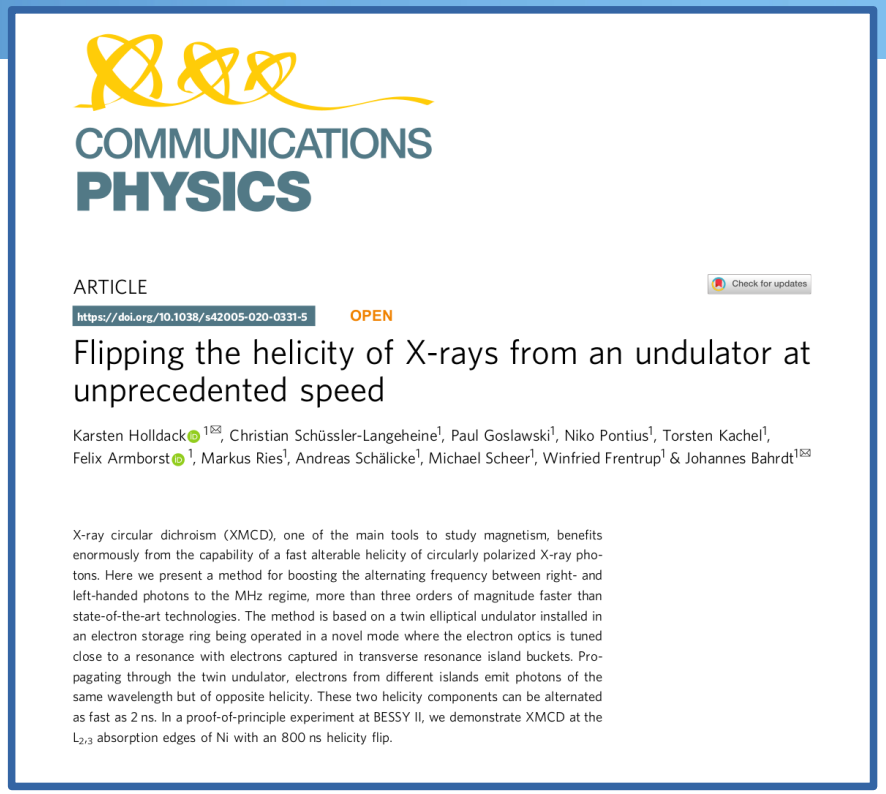
See BESSY VSR homepage
https://www.helmholtz-berlin.de/media/media/zentrum/perspektiven/vsr/report-kw082018-twoorbittribsweek-final.pdf

HZB TRIBs Summary/History

2020

XMCD@TRIBs at BESSY II

MHz Helicity Flipping



COMMUNICATIONS PHYSICS

ARTICLE

https://doi.org/10.1038/s42005-020-0331-5 OPEN

Flipping the helicity of X-rays from an undulator at unprecedented speed

Karsten Holldack[1✉], Christian Schüssler-Langeheine[1], Paul Goslawski[1], Niko Pontius[1], Torsten Kachel[1], Felix Armborst[1], Markus Ries[1], Andreas Schälicke[1], Michael Scheer[1], Winfried Frentrup[1] & Johannes Bahrdt[1✉]

X-ray circular dichroism (XMCD), one of the main tools to study magnetism, benefits enormously from the capability of a fast alterable helicity of circularly polarized X-ray photons. Here we present a method for boosting the alternating frequency between right- and left-handed photons to the MHz regime, more than three orders of magnitude faster than state-of-the-art technologies. The method is based on a twin elliptical undulator installed in an electron storage ring being operated in a novel mode where the electron optics is tuned close to a resonance with electrons captured in transverse resonance island buckets. Propagating through the twin undulator, electrons from different islands emit photons of the same wavelength but of opposite helicity. These two helicity components can be alternated as fast as 2 ns. In a proof-of-principle experiment at BESSY II, we demonstrate XMCD at the $L_{2,3}$ absorption edges of Ni with an 800 ns helicity flip.

KW44, Calender Week 44, 26.10. - .11.2020

–> The next Two Orbit / TRIBs User Week

A normal user week from Tuesday afternoon / evening on !

XMCD @ TRIBs at BESSY II: Fast helicity switching

K. Holldack,
J. Bahrdt et al.

- X-ray magnetic circular dichroism (XMCD)
  - is a important application at synchrotron facilities to study magnetic properties (spin & orbital magnetic moment) of probes
    (magnetic recording materials, quantum materials, clusters, spintronics & catalysis)
  - different absorption of polarized X-rays on atomic orbitals, in case of transition metals (iron, cobalt, nickel: 700-900 eV) measured at L-edge
  - fits perfect to BESSY II, because of our UEXX (elliptical APPLE II)
  - Studies of dynamical process and experiments addressing small effects like in molecular spin systems, on surfaces, spatially resolved magnetic domains and quasi-particles in solids would benefit enormously from the capability of a **fast alterable helicity switching: S/N ratio ~ switching freq.**
  - In the soft X-ray regime polarization must be flipped within the undulator
  - Double undulator systems
    with static orbit bumps and chopper (~100 Hz)
    with dynamic orbit kicks (10 Hz)

Method: XMCD

X-ray Magnetic Circular Dichroism

Station	Energy Range	Polarisation	Beamline	Contact
ALICE	20 - 1900 eV	• horizontal • circular	Soft X-ray dipole variable polarisation with PGM open port + scattering chamber	
	85 - 1600 eV	horizontal	U49-2_PGM-1 Undulator PGM horizontal polarisation	
	100 - 1500 eV	variable	Soft X-ray undulator radiation variable polarization with SGM and resonant bunch excitation for open	
	60 - 1300 eV	• linear horizontal vertical • circular	Soft X-ray fs-to-ps pulsed undulator radiation variable polarization with PGM for FEMTOSPEX Surface	
	60 - 1300 eV	• horizontal • vertical • circular	UE56-2_PGM-1	
	60 - 1300 eV	• horizontal • vertical • circular	UE56-2_PGM-2	
	20 - 690 eV	variable	XUV undulator radiation variable polarization with PGM for meV RIXS + open port	
	eV		search a beamline for me	
FEMTOSPEX-DynaMax	410 - 1333 eV	variable	Soft X-ray fs-to-ps pulsed undulator radiation variable polarization with Zone Plate Mono for FEMTOS	Christian Schüßler-Langeheine Niko Pontius Karsten Holldack Torsten Kachel
FEMTOSPEX surface dynamics	60 - 1300 eV	• linear horizontal vertical • circular	Soft X-ray fs-to-ps pulsed undulator radiation variable polarization with PGM for FEMTOSPEX Surface	Nomi Sorgenfrei Hikmet Sezen Erika Giangrisostomi Stefan Neppl
High-Field Diffractometer	120 - 2000 eV	• linear any angle (with restrictions) • circular	UE46_PGM-1	Eugen Weschke Enrico Schierle
LEEM-PEEM	55 - 1500 eV	• horizontal • vertical • circular	UE56-1_SGM	Stefan Cramm
MAXYMUS	150 - 1900 eV	Horizontal, Vertical, Circular positive, Circular negative	UE46_MAXYMUS	Michael Bechtel
VEKMAG	eV	Circular, Horizontal	Vektor Magnet	Florin Radu

Helicity switching of circularly polarized undulator radiation by local orbit bumps

T. Hara[a,b,*], K. Shirasawa[c], M. Takeuchi[b], T. Seike[b], Y. Saito[d], T. Muro[b], H. Kitamura[a,b]

[a] SPring-8/RIKEN, 1-1-1 Kouto, Mikazuki-cho, Sayo-gun, Hyogo 679-5148, Japan

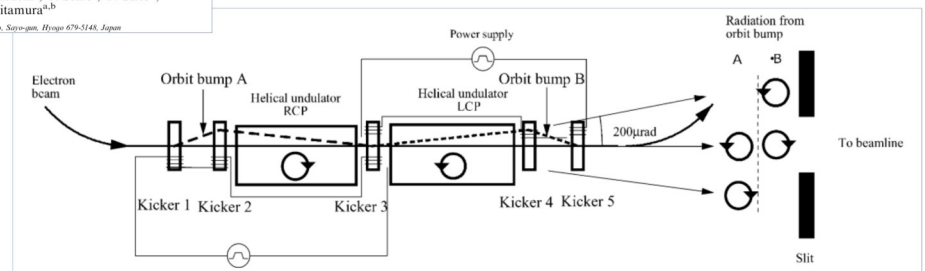
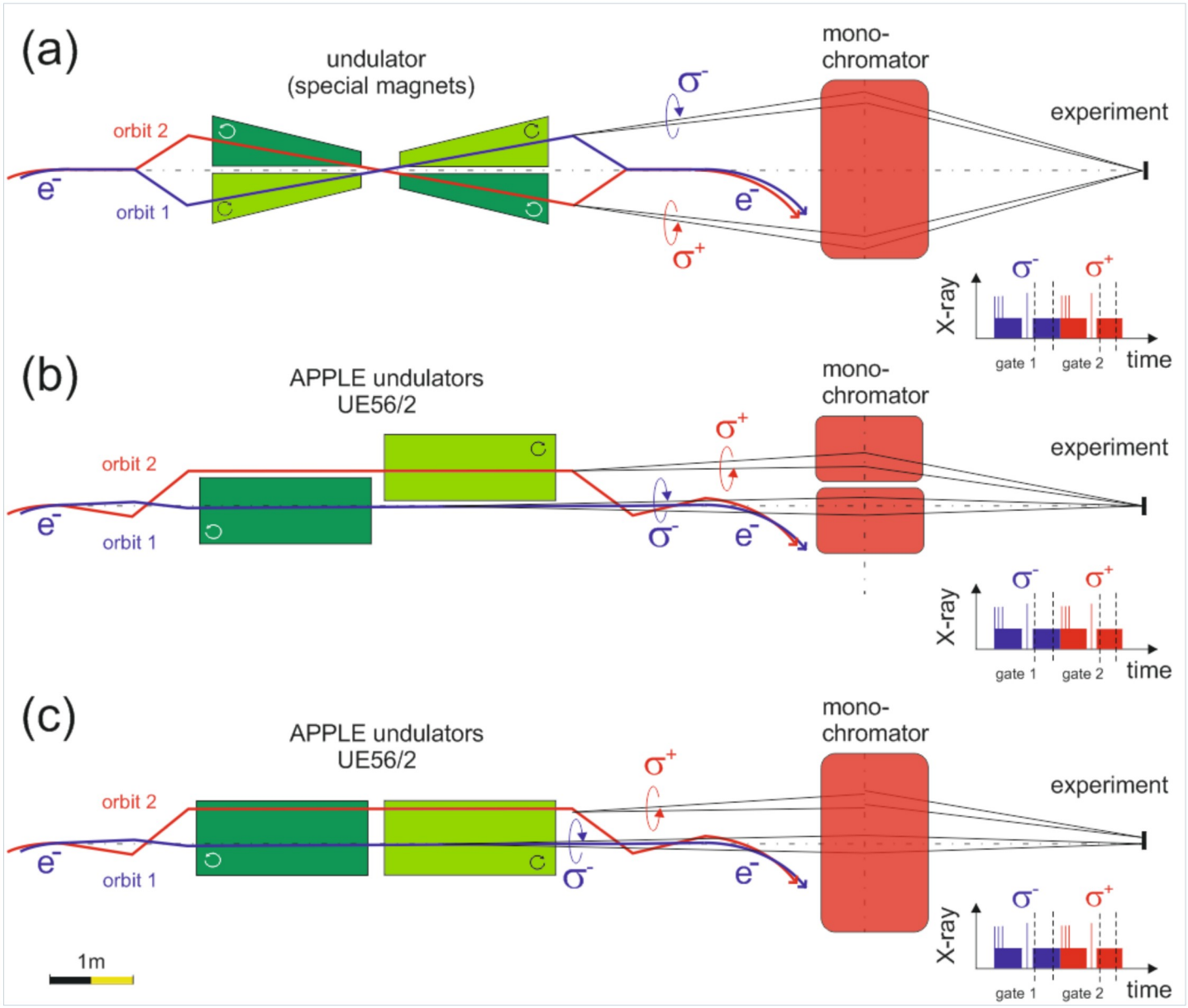


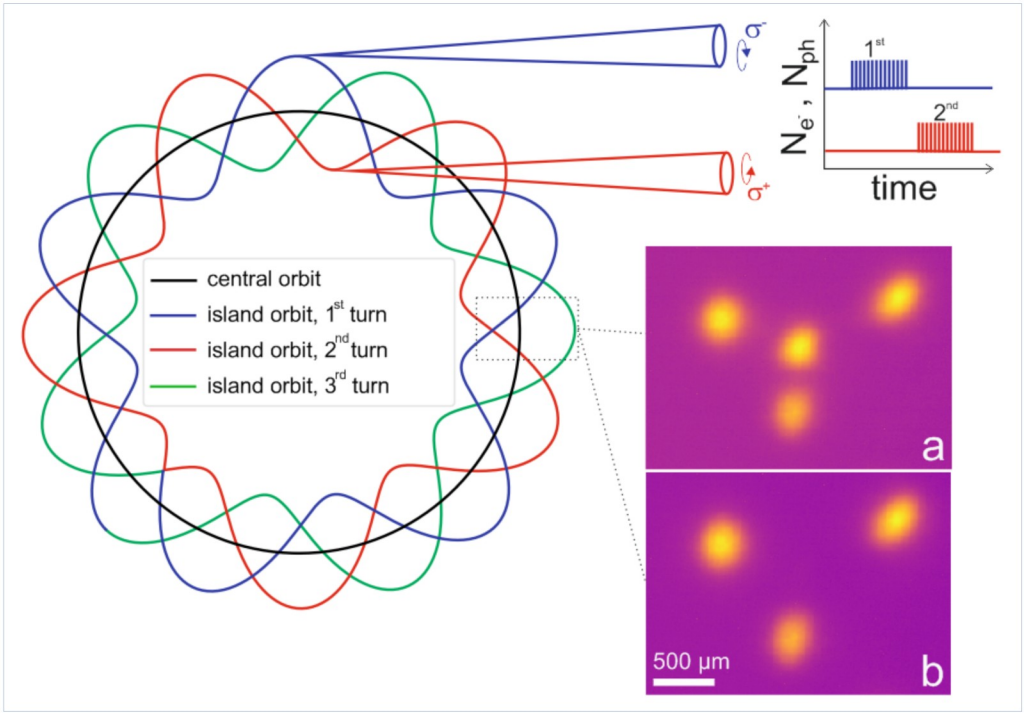
Fig. 2. Electron beam orbit bumps A (broken line) and B (dotted line) generated by five kicker magnets (top view). When orbit bump A (B) is generated, left (right) circular light is emitted on axis and supplied to the beamline.

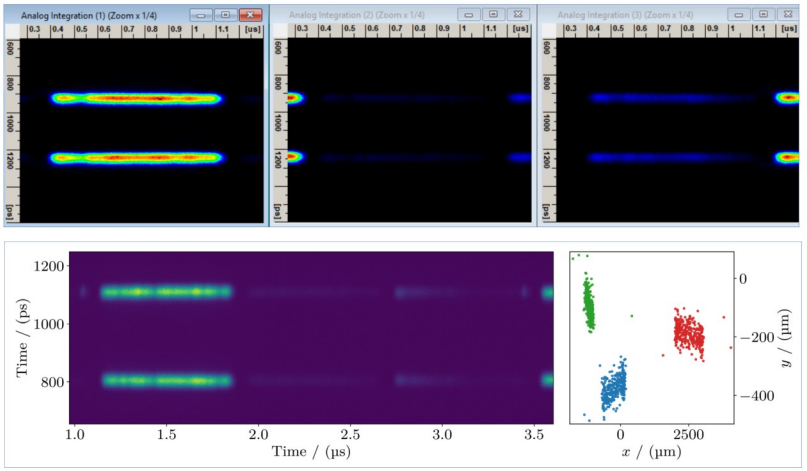
TRIBs Experimental Applications: Fast helicity switching

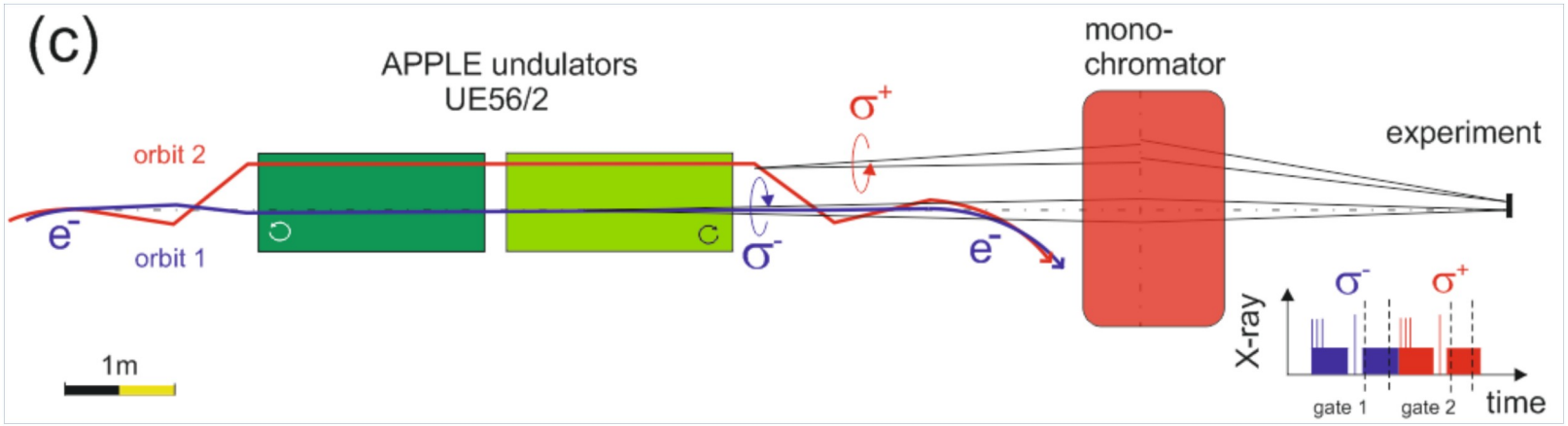


XMCD @ TRIBs at BESSY II: Fast helicity switching

K. Holldack,
J. Bahrdt et al.







XMCD @ TRIBs at BESSY II: Fast helicity switching

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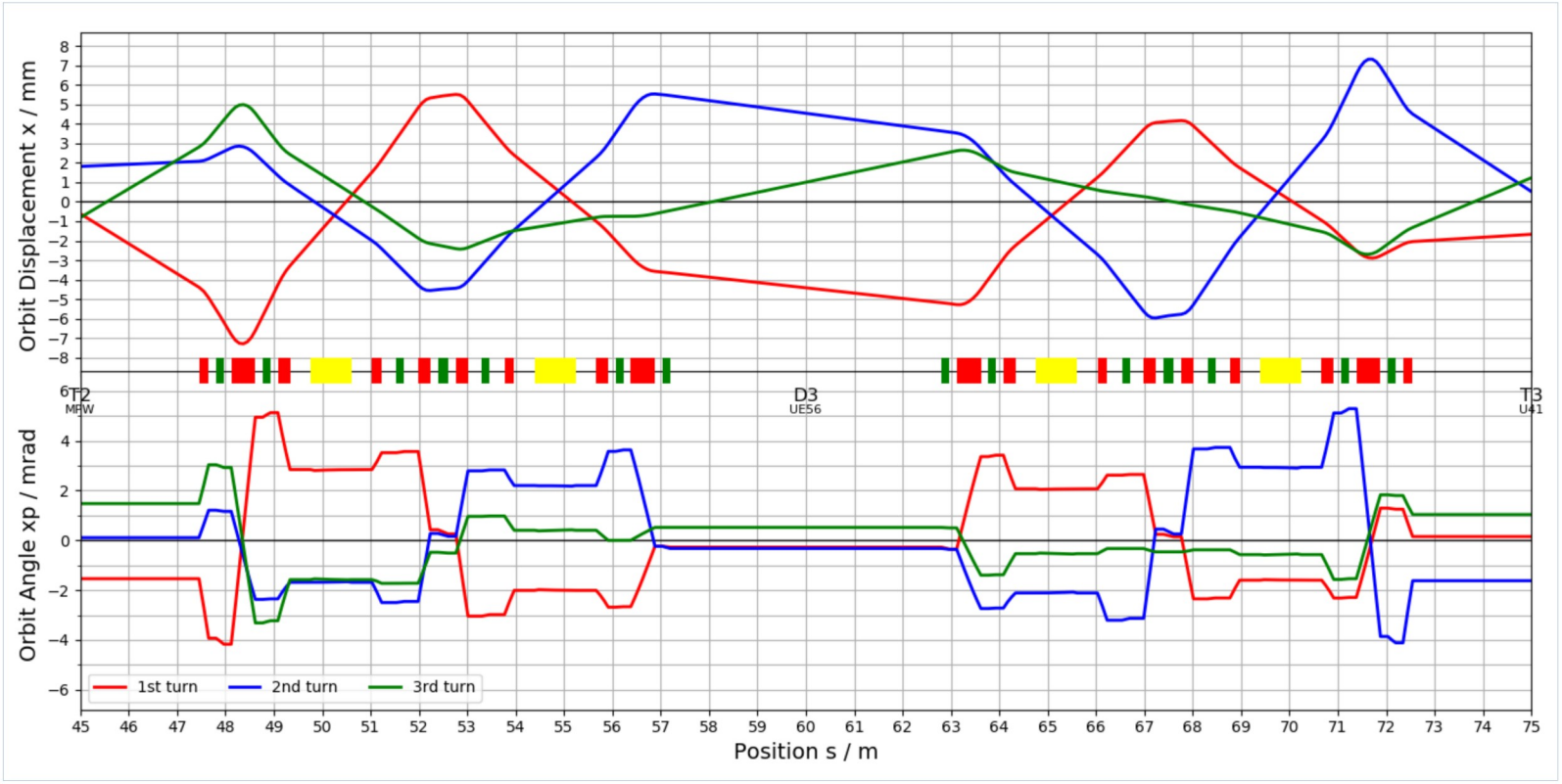
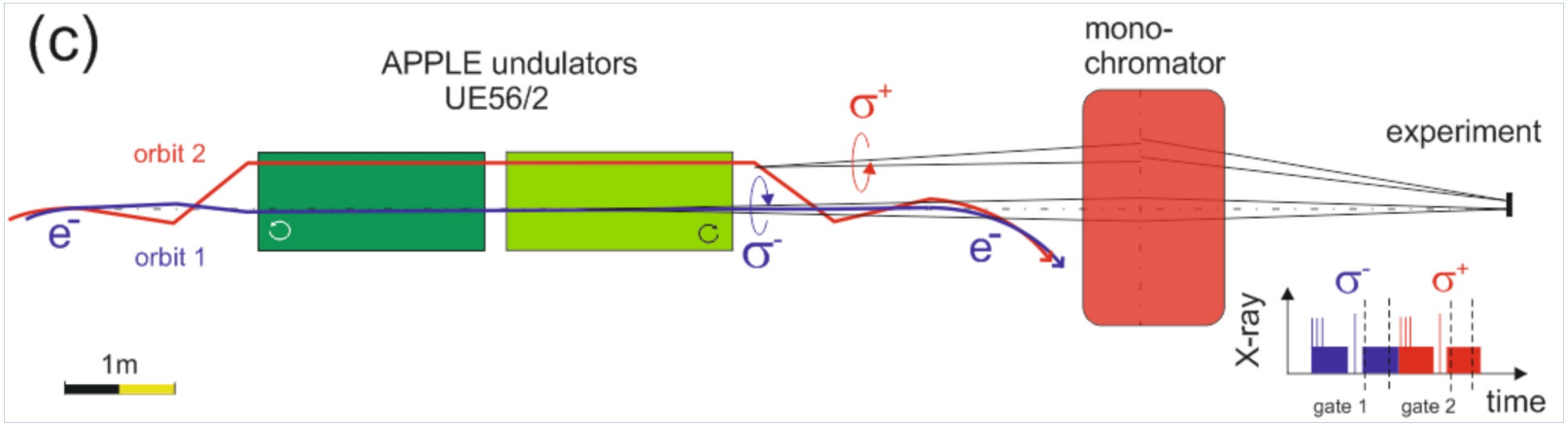
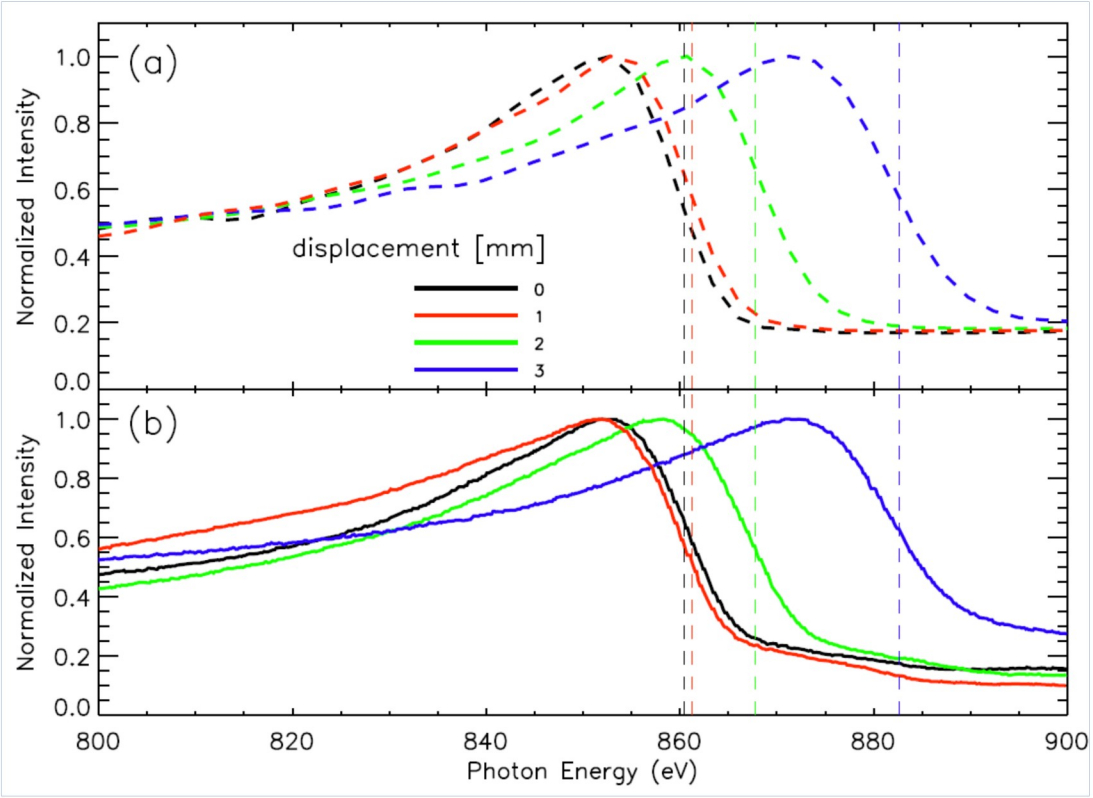
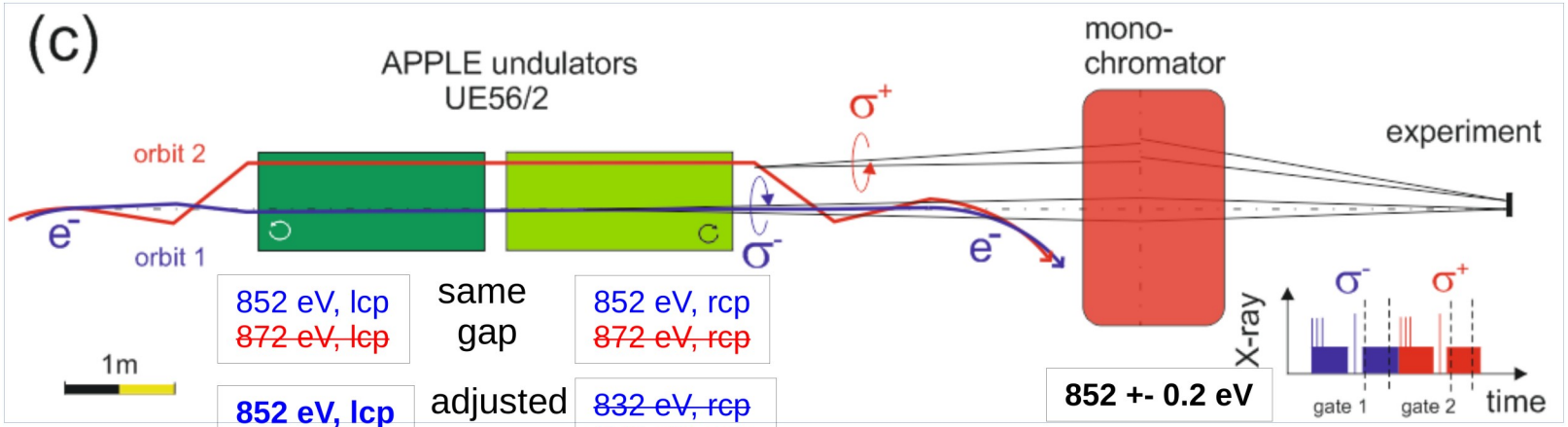




XMCD @ TRIBs at BESSY II: Fast helicity switching



- Difference for an off axis beam of 3 mm results in energy shift of 20 eV measured at a Permalloy sample ($Ni_{80}Fe_{20}$) sample at the Ni L_3-edge (850 eV)
- Spectral window of monochromator at 200 meV



XMCD @ TRIBs at BESSY II: Fast helicity switching

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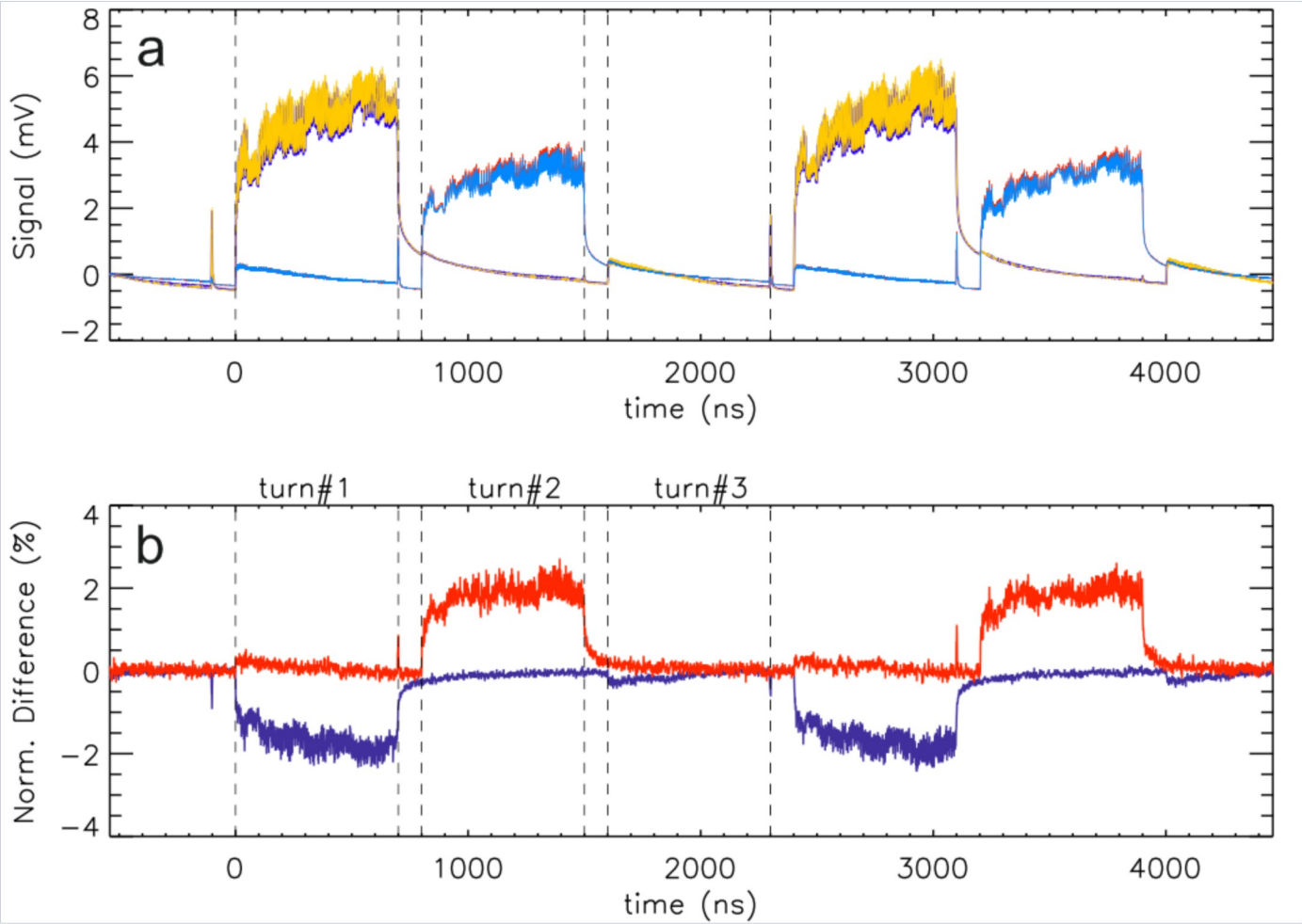

As detector a fast Avalanche Photo Diode (APD) was used and the signal from 1st and 2nd revolution have been sorted by a digital oscilloscope.

XMCD @ TRIBs at BESSY II: Fast helicity switching

K. Holldack,
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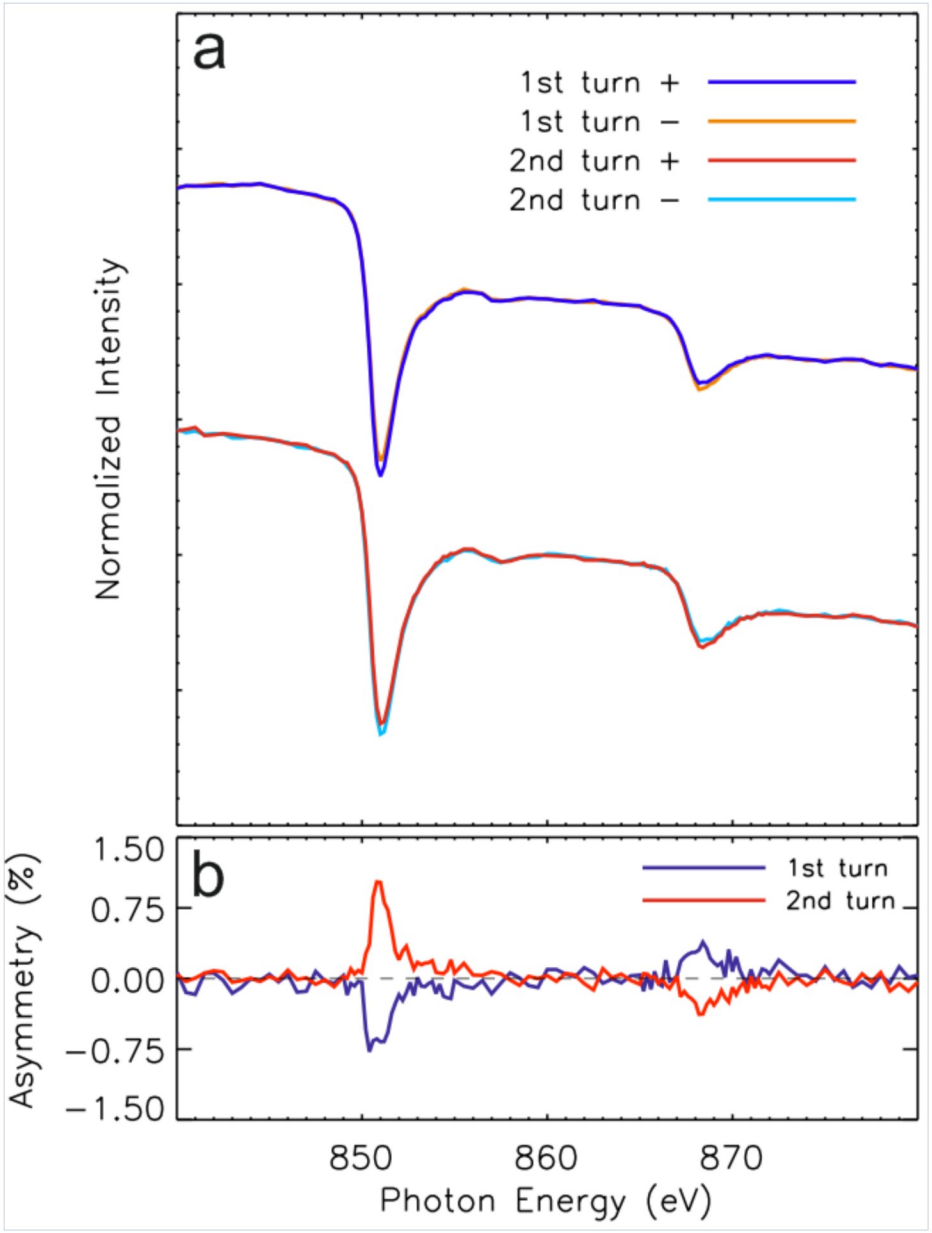
To demonstrate an usual XMCD measurement at the selected settings, the mean values of the signals from the 1st and 2nd gate-windows from the previous figure are now displayed during an energy scan **(combined undulator-monochromator ride with magnetic field alternation).**

The XMCD difference-over-sum signal clearly shows that the helicity is reversed between the two turns.

Turn-By-Turn flip ~ 1.25 MHz of the X-ray helicity from an undulator at an electron storage ring

TRIBs Experimental Applications: Fast helicity switching



Summary, Conclusions

MHz-fast Helicity Flipping of Undulator Radiation

TRIBs for

1) BESSY II
2) BESSY III

3) … others?

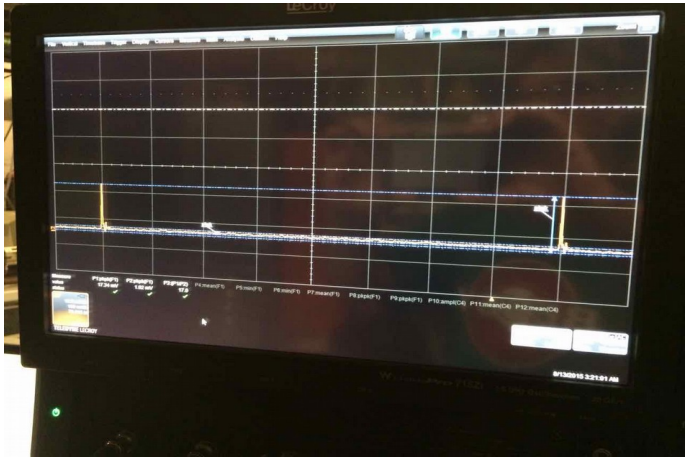
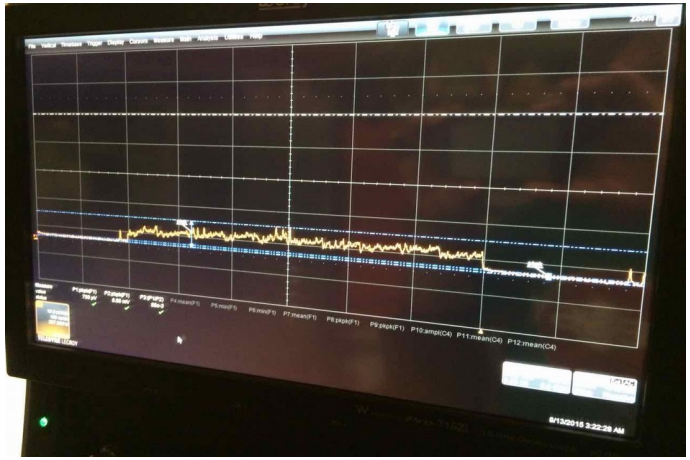
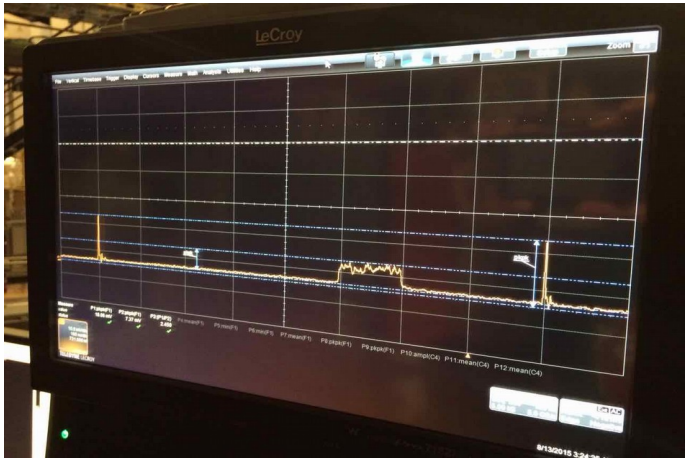
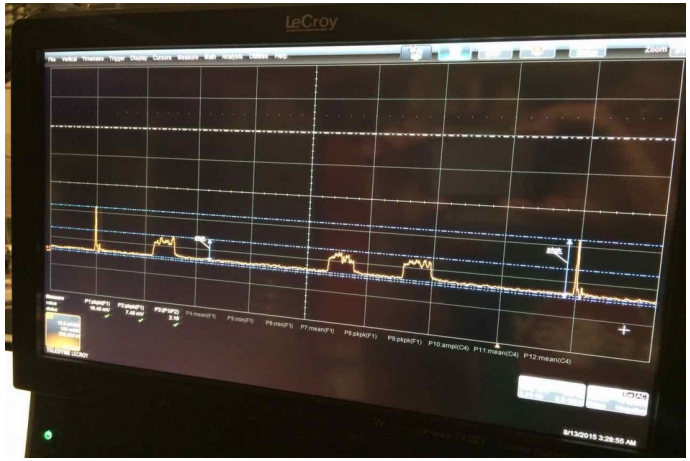
- Proof of principle of a **turn-by-turn flip** (of 800 ns) of the X-ray helicity from an electron storage ring, which is the **highest alternation frequency of 1.25 MHz** ever reported.
- Demonstrated a **stable operation** of a light source in TRIBs setting combined with state-of-the-art helical undulator technology and **successful fast magnetism experiments** behind a beamline.
- The method if improved opens new magnetism experiments towards tiny magnetic moments, microscopy and MHz dynamics
- We believe that **ultra-low emittance light sources** with tailored IDs might be suited to improve and use our method in the future

Fore more details see:

K.Holldack, C. Schüssler-Langeheine, P.Goslawski, N.Pontius,
T.Kachel, F.Armborst, M.Ries, A.Schälicke, M.Scheer, W.Frentrup, J.Bahrdt

Flipping the helicity of X-rays from an undulator at unprecedented speed, Comm.Phys. **3**, 61 (2020),
https://www.nature.com/articles/s42005-020-0331-5.pdf or https://doi.org/10.1038/s42005-020-0331-5

Thank you for your attention

Thanks to all internal and external Colleagues & Users contributing to TRIBs

References, Team and Acknowledgement for all TRIBs dev.

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K. Holldack et al., *Flipping the helicity of X-rays from an undulator at unprecedented speed*, Comm.Phys. **3**, 61 (2020), https://www.nature.com/articles/s42005-020-0331-5.pdf or https://doi.org/10.1038/s42005-020-0331-5

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M. Ries et al., "Transverse Resonance Island Buckets at the MLS and BESSY II"
Proceedings of IPAC2015, Richmond, VA, USA, MOPWA021

Team

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Felix Armborst (Kramer), P. Goslawski, M. Ries, G. Schiwietz, G. Wüstefeld

Beamline Scientists and Users:
K. Holldack, F. Kronast, R. Ovsyannikov, E. Schierle, G. Schönhense and others

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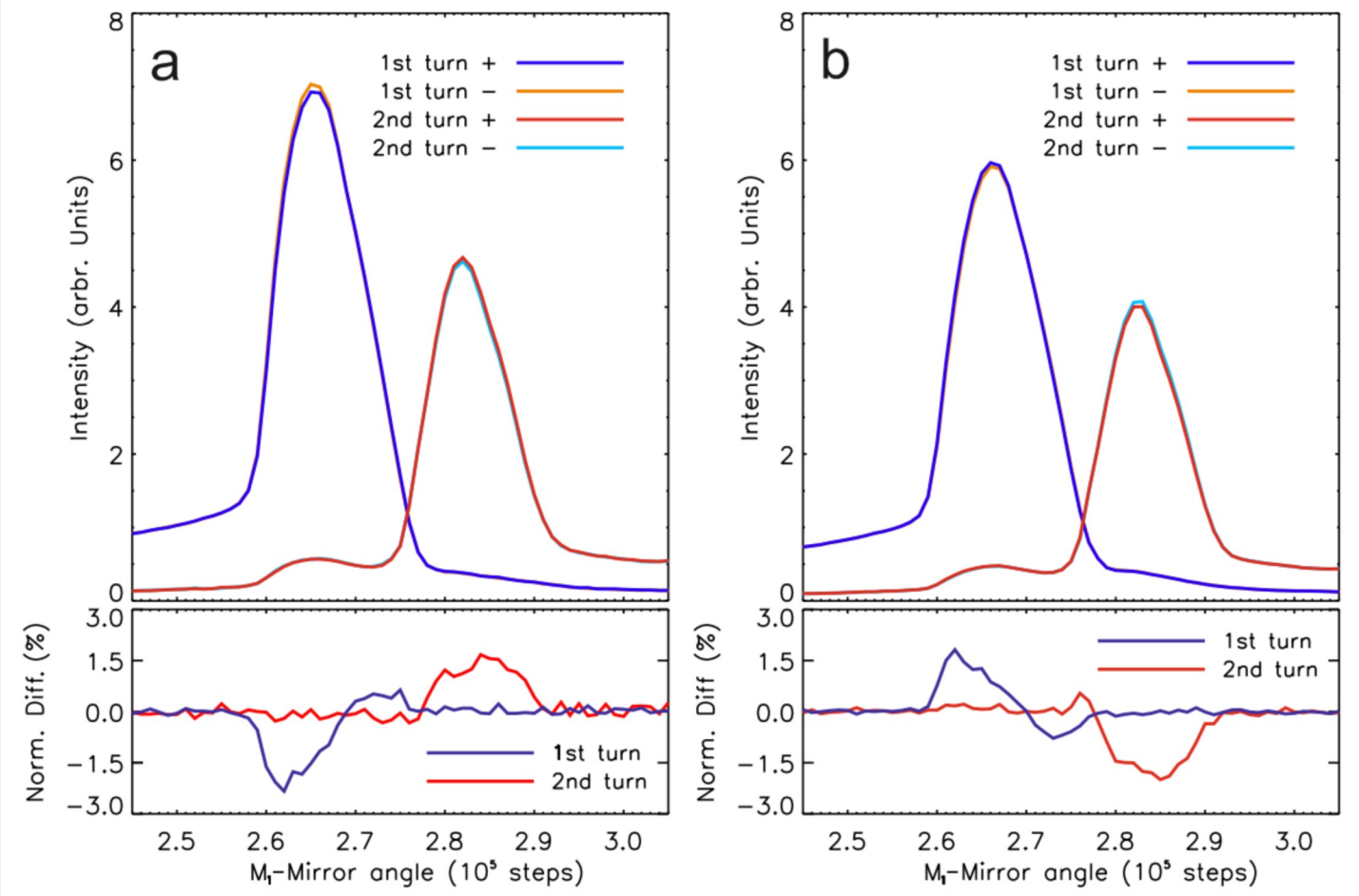
G. Schönhense for the few bunch mode and his TRIBs motivation
S. Khan and A.S. Müller for our Proposal: TiMo – Timing Modes for Advanced Lightsources
D.K. Olsson, Å. Anderson & P. Tavares for the opportunity to test at MAX IV's 3 GeV MBA ring.

Back Up

XMCD @ TRIBs at BESSY II: Fast helicity switching

K. Holldack,
J. Bahrdt et al.



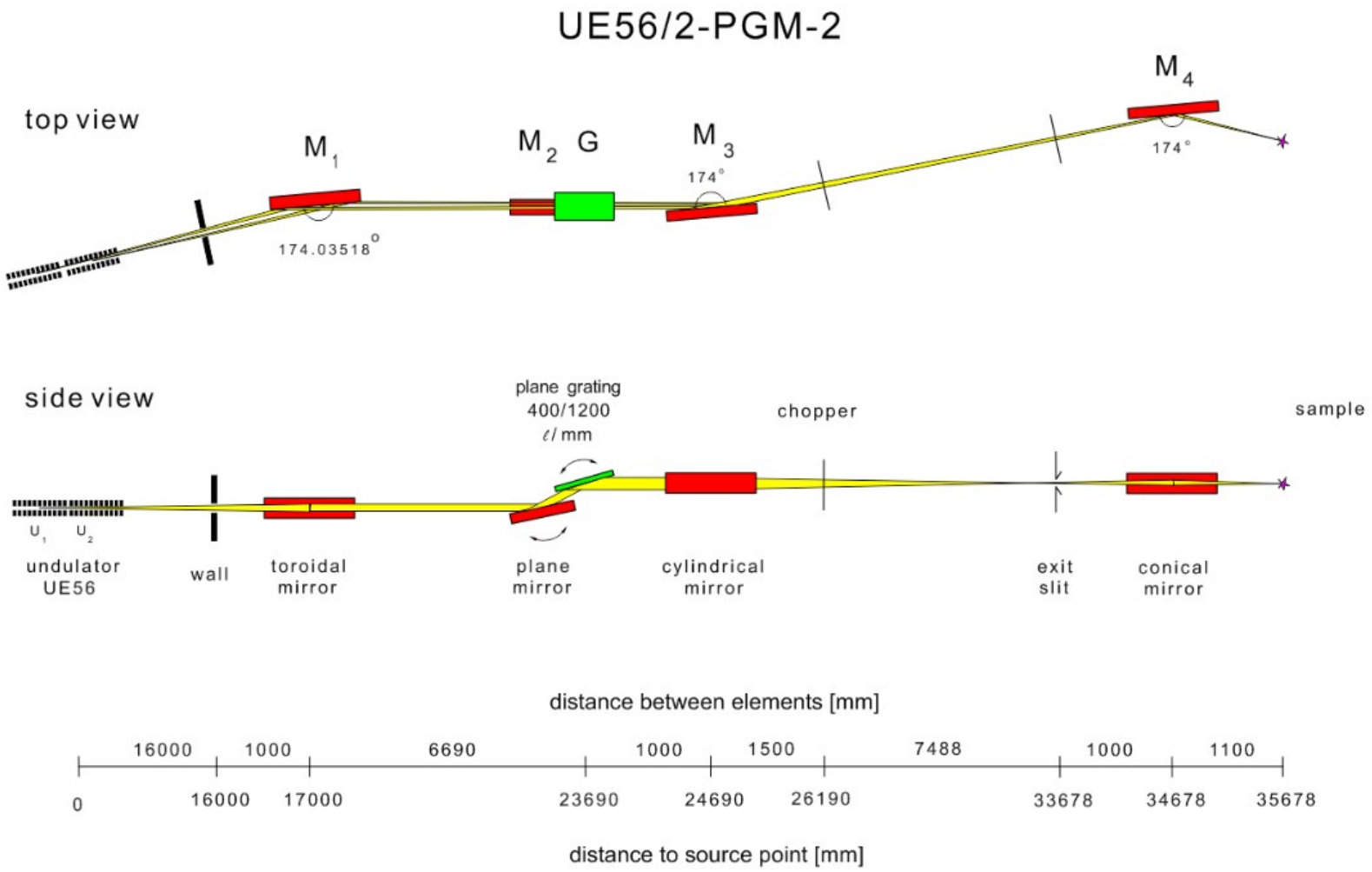
XMCD effect was detected in Permalloy sample ($Ni_{80}Fe_{20}$) at the Ni L_3-edge magnetized along the beam direction using an electromagnet.

Shifts/Helicity have been changed between a & b

Distance between the two spots 3.7 mm.

XMCD @ TRIBs at BESSY II: Beamline

K. Holldack,
J. Bahrdt et al.

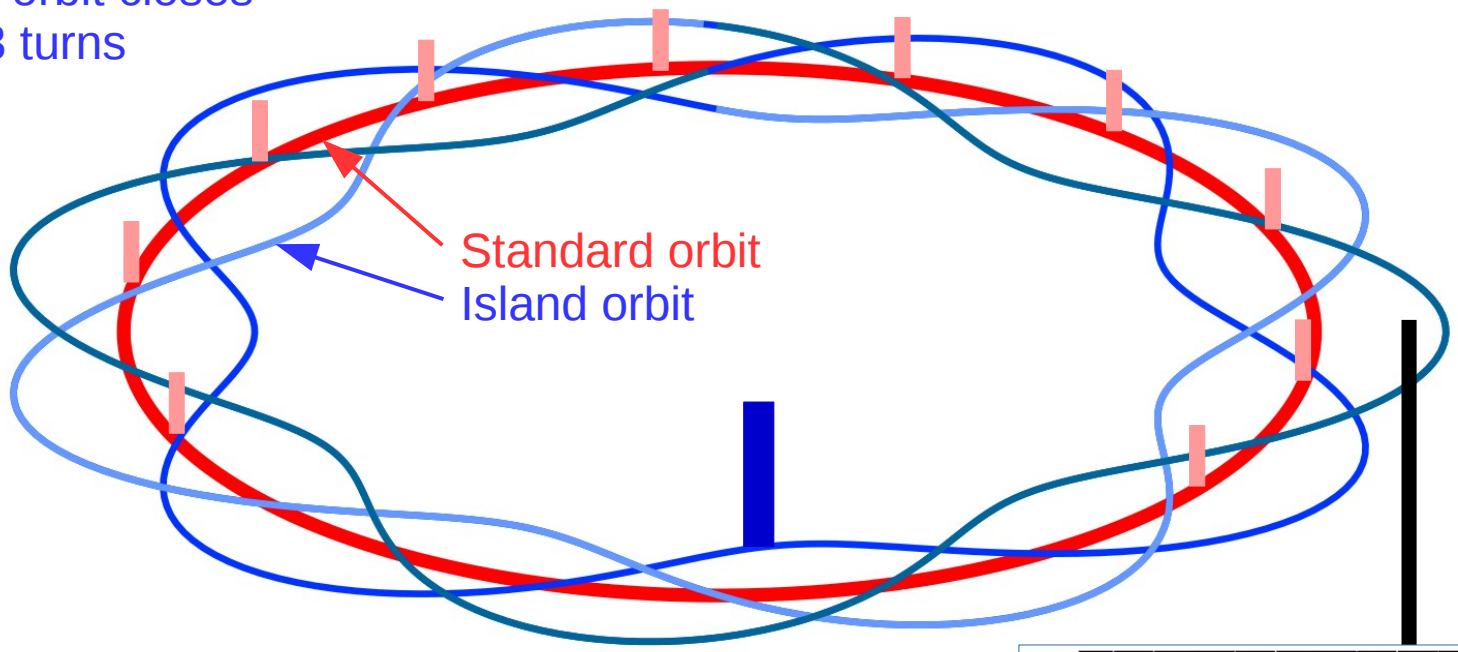


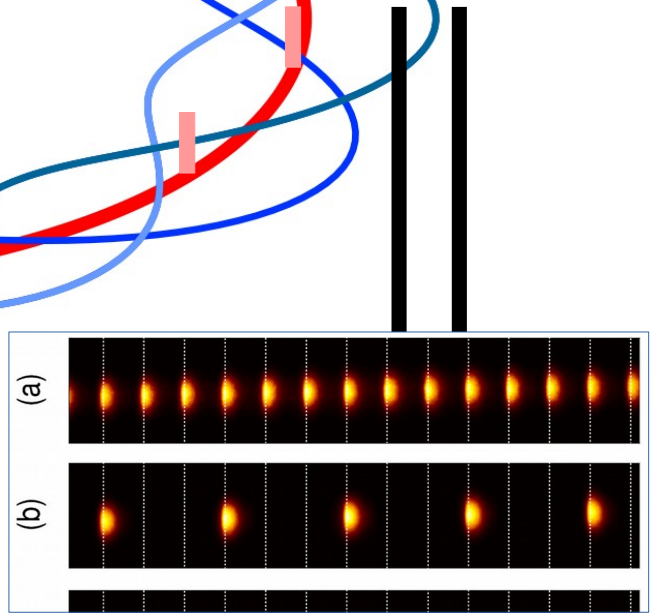
Supplementary Figure 5 | Beamline optical layout of the UE56-2 PGM monochromator[3]. Mirror M_1 performs a horizontal image of the source point in the high beta section onto the sample at a slight magnification of M = 1.049.

Application: “Increase Revolution Time”

2nd stable orbit with **T**ransverse **R**esonance **I**sland **B**uckets - **TRIBs**

3rd order resonance
Island orbit closes
after 3 turns





Streak camera with aperture
to select photons of one island

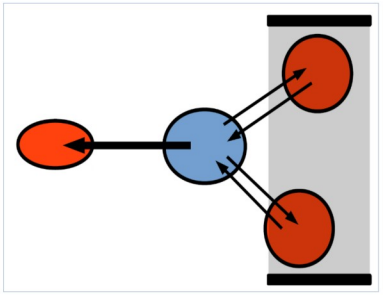
Increasing revolution time, decreasing revolution frequency

- By the factor = order of resonance
- Decreasing repetition rate at small storage rings for TOF exp.
- **Proof-of-principle User Experiment at the MLS**
  (see T. Arion et. al., Rev. Sci. Instrum. 89, 103114 (2018))

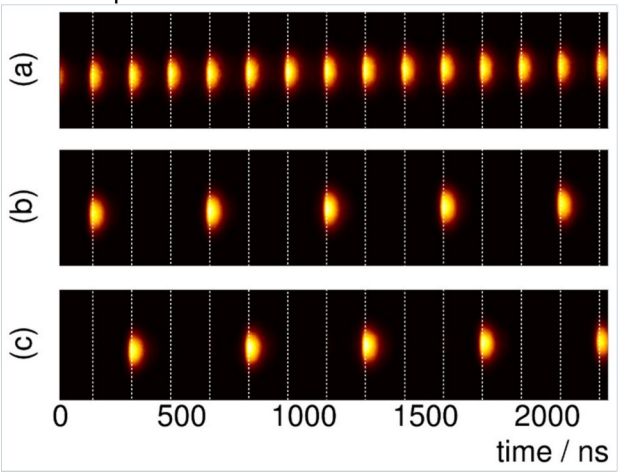
First successful user experiment at MLS (2015)

Current manipulation, sub-revolution frequency

- How to populate only one island?
- Non linearity of stripline kicker
- Kick (or pause) every 3rd turn:
  2.083 MHz instead of 6.25 MHz
  pause-pause-kick

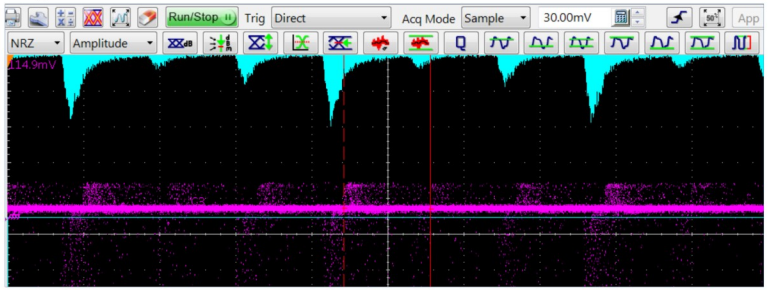


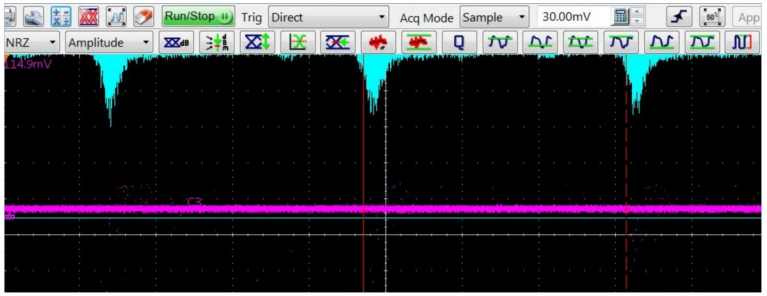
Streak camera with aperture
to select photons of one island



a) islands equally populated, kick every turn
b, c) only single island populated, pause-pause-kick
kick every 3rd turn

Signal measured at ID beamline with channeltron





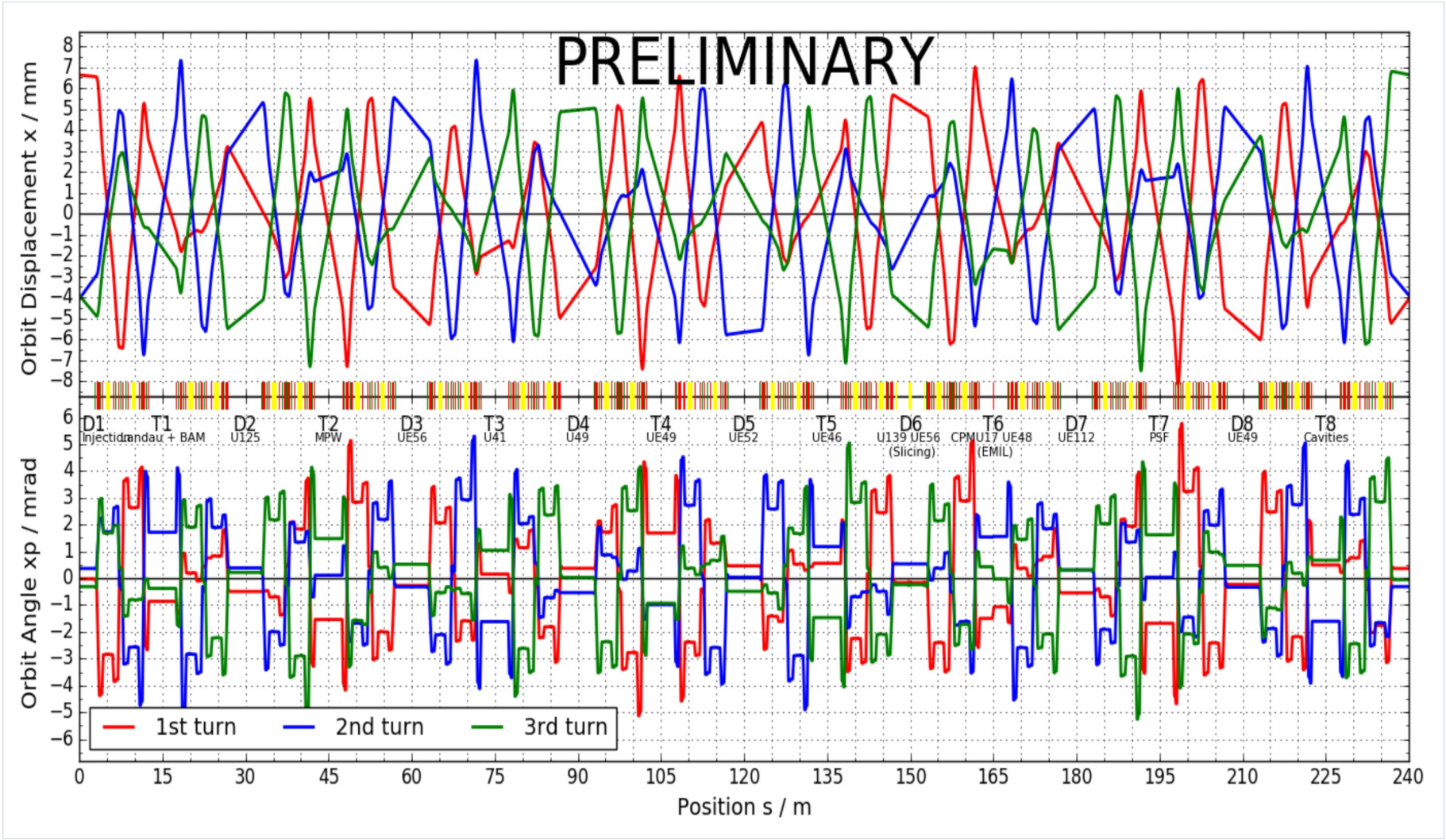
First successful user experiment

- ARTOF spectrum at photon energy of 44 eV
  of Au(111) single crystal sample
- Reduced revolution frequnecy of 6.25 MHz to
  2.083 MHz (revolution time 160 ns to 480 ns)
- Two successful user runs of 10 h each in decay mode
- Vertical and horizontal position shows good long term
  stability of island orbit

- Paper in preparation
- MLS access perfect for development and first tests

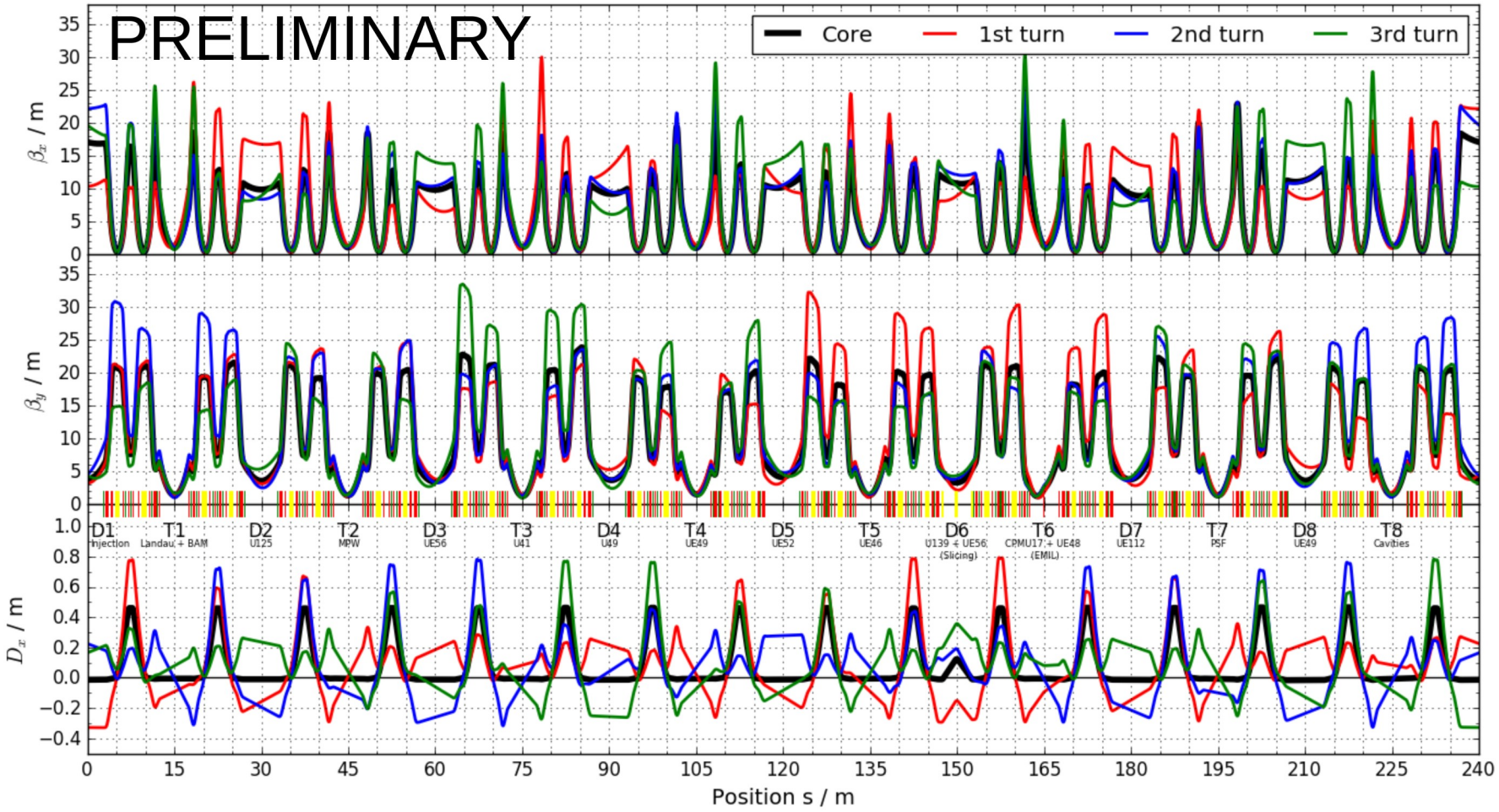
TRIBs at BESSY II: Separation at beam lines

Separation – Orbit Displacement and Angle for 2nd Island Orbit



Separation: > 10σ at horizontal source size of σ_x ~ 300 mm and divergence of maximal σ_x' ~ 0.3 m rad

TRIBs at BESSY II: Optical Functions & Emittance



Emittances:

B2 standard user mode:	**7.6**	**nm rad**
B2 TRIBs core orbit:	**7.7**	**nm rad**
B2 TRIBs island orbit:	8.0 - 14 nm rad	

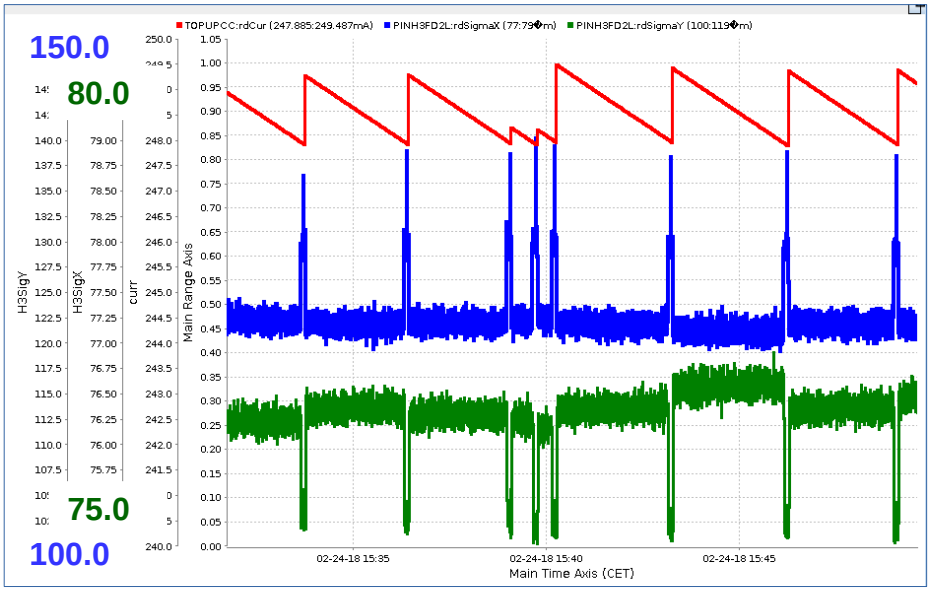
$$\sigma = \sqrt{\beta \cdot \epsilon + (D \cdot \delta)^2)}$$

Source size on island orbit increases by a factor of < 2

Injection into BESSY II's TRIBs optics: Injection distortion

- Comparison between Feb 2018 (one drive) and Nov 2019 (three drives)

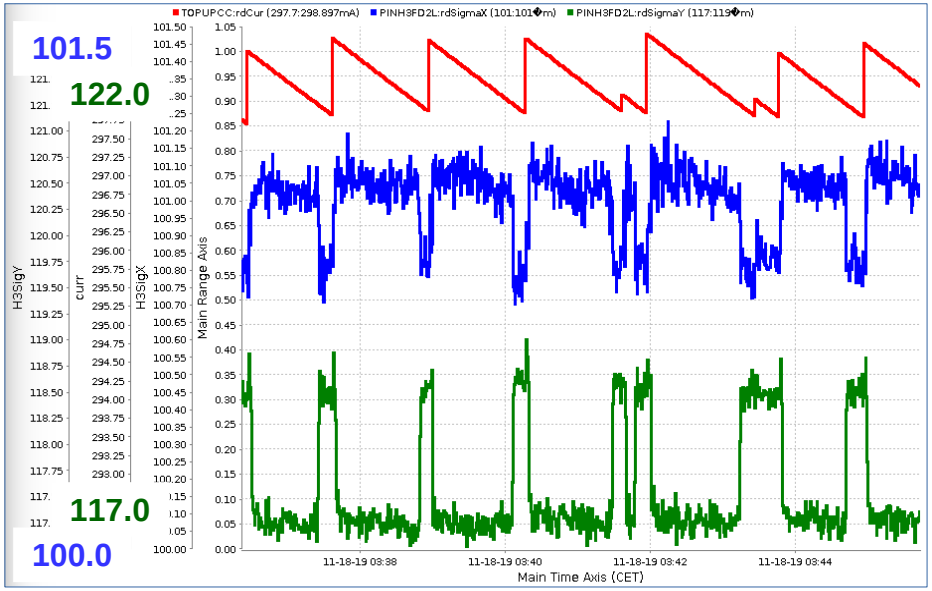
February 2018



Horizontal sources size increases by 16-20%

Vertical source size decreases by 2-3 %

November 2019

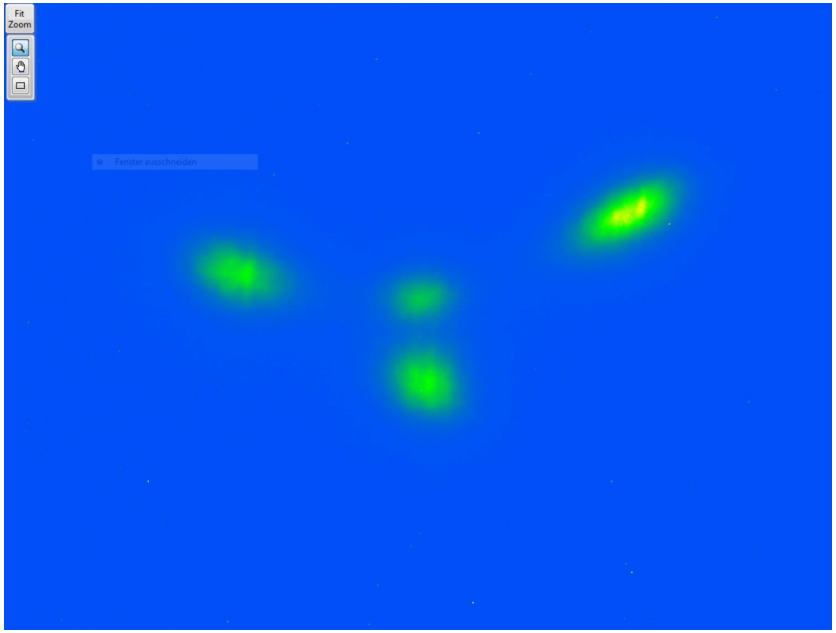


Horizontal sources size decreases by < 1%

Vertical source size increases by ~ 1 %

All spots in x-plane

TRIBs 2018



TRIBs 2020