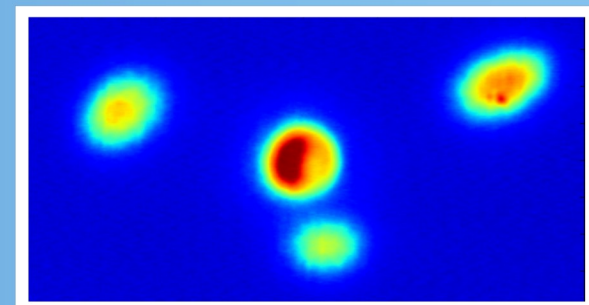


Two Beam Operation at Storage Ring Light Sources

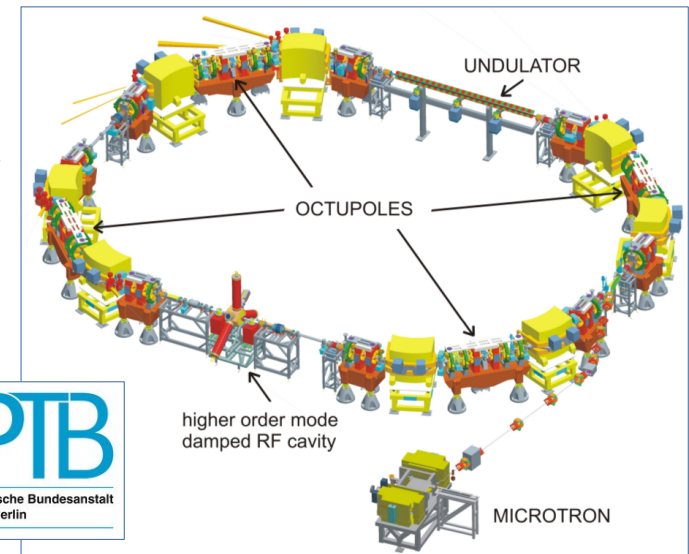
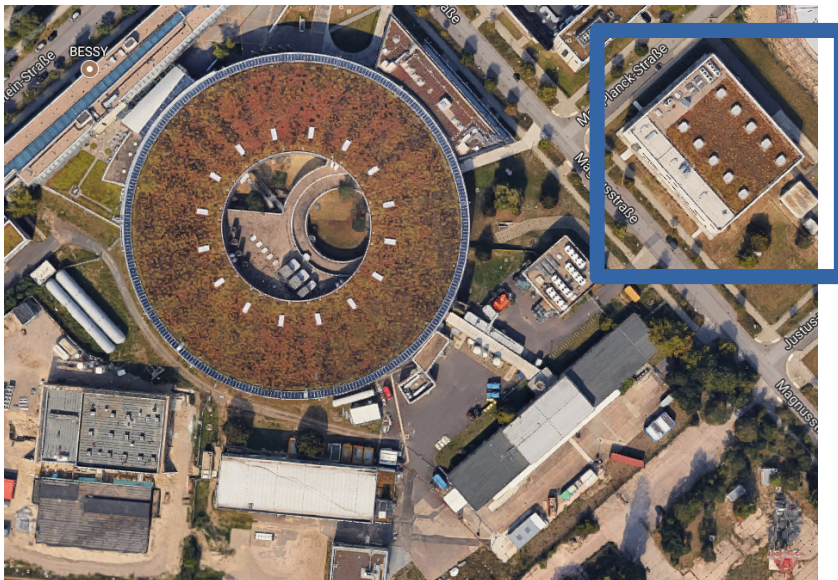
TRIBs (Transverse Resonance Island Buckets) at BESSY II / MLS

P. Goslawski, M. Ries et al.
Institut for Accelerator Physics
Helmholtz-Zentrum Berlin

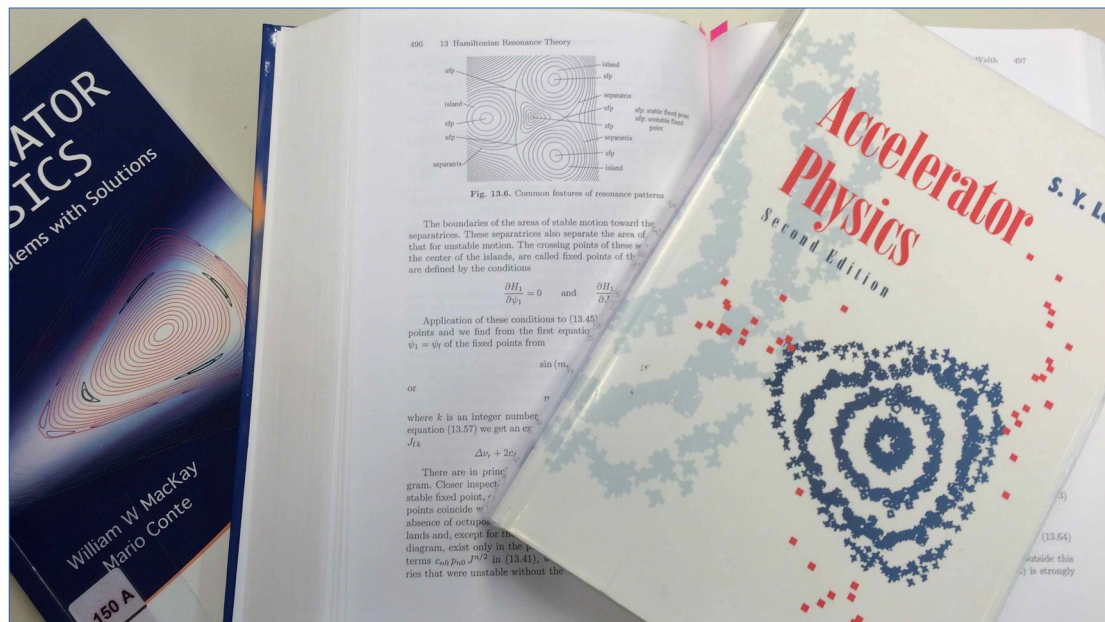


- Motivation
 - Why TRIBs at BESSY II and MLS (Metrology Light Source) ?
 - TRIBs for BESSY VSR ?
- Transverse Resonance Island Buckets – TRIBs at HZB, i.e., at BESSY II and MLS
 - Studies, Experiments and Application

HZB Helmholtz
Zentrum Berlin



PTB
Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin



No Application at Lightsources so far

- Do not store beam on resonance
- “Accelerator operators are keen to avoid low order strong resonances because of visibly short lifetime.”
- “Accelerator physicists are eager to to apply their skill to correct or compensate the resonance for minimizing their effects on the beams.”

Accelerator Physics, S.Y. Lee

Application: Multiturn (slow) extraction

- R.Cappi and M.Giovanozzi, “Multiturn extraction and injection by means of adiabatic capture in stable islands of phase space”, Phys. Rev. ST Accel. Beams 7, 024001 (2004)

“Realizing the benefits of restored periodicity in the advanced light source”
D.Robin, J.Safranek, W.Decking PRST-AB 2, 044001 (1999)

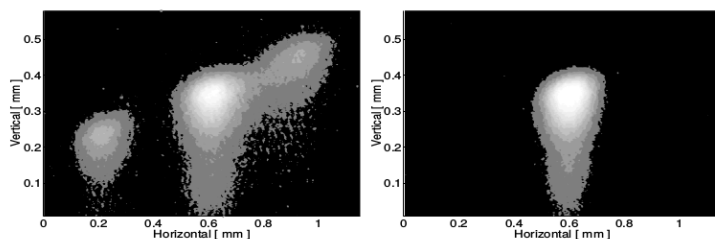
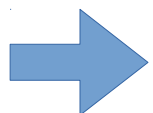


FIG. 14. Synchrotron radiation image of the beam near the $3\nu_x$ resonance. Left is the situation before the optic is corrected and right is the situation after the optic is corrected. (The plane of the camera is rotated with respect to the plane of the beam.) Also there is a distortion in the light optic in the vertical plane that is responsible for the image's vertical asymmetry.

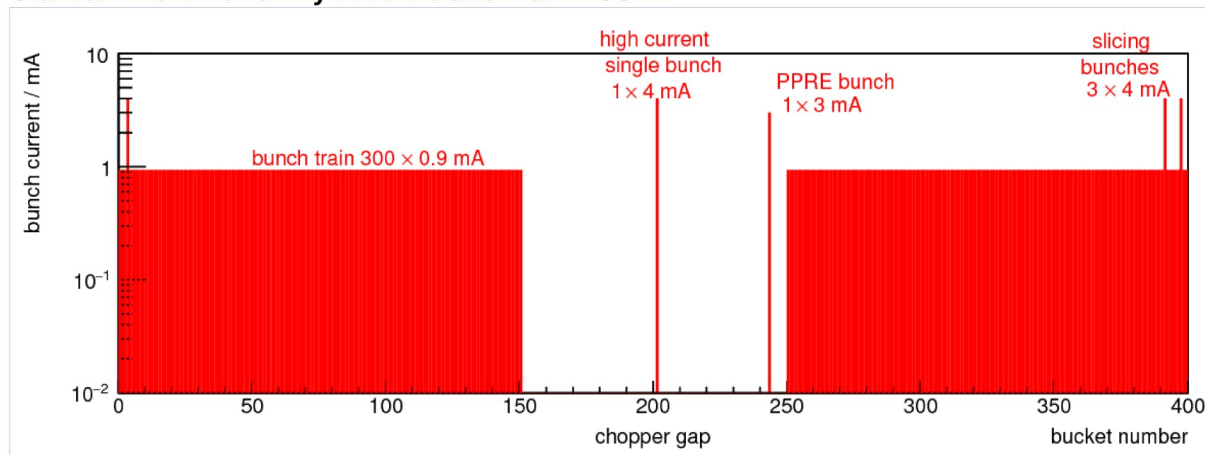


Stable 2nd closed orbit for bunch separation
Aim: Multiple beam storage with island buckets

Motivation: Electron Bunch Separation Schemes to serve the

broad diverse user community
with different requirements,
simultaneously !

Standard Multi Bunch Hybrid Fill Pattern at BESSY II



In addition:

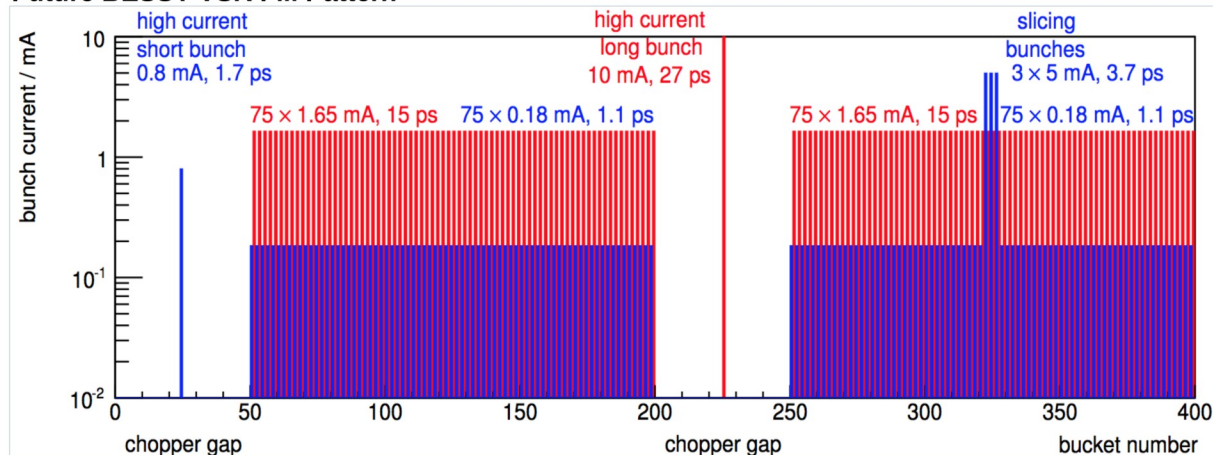
Single Bunch mode 2-3 weeks per year

Few Bunch mode 2-3 days per year

Low alpha mode 2 weeks per year

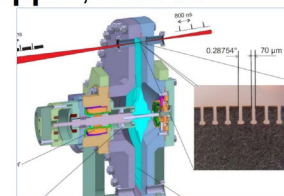
See – https://www.helmholtz-berlin.de/quellen/bessy/betrieb-beschleuniger/betriebsmodi_en.html
or google: BESSY II operation modi

Future BESSY VSR Fill Pattern

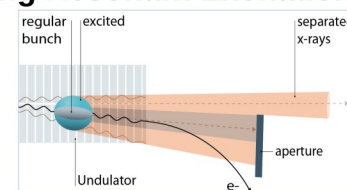


Pulse separation schemes

- X-ray MHZ Chopper**, local at beam lines, photon pulse separation (FZJ, HZB)



- Pulse Picking Resonant Excitation PPRE**, e^- bunch separation (HZB)

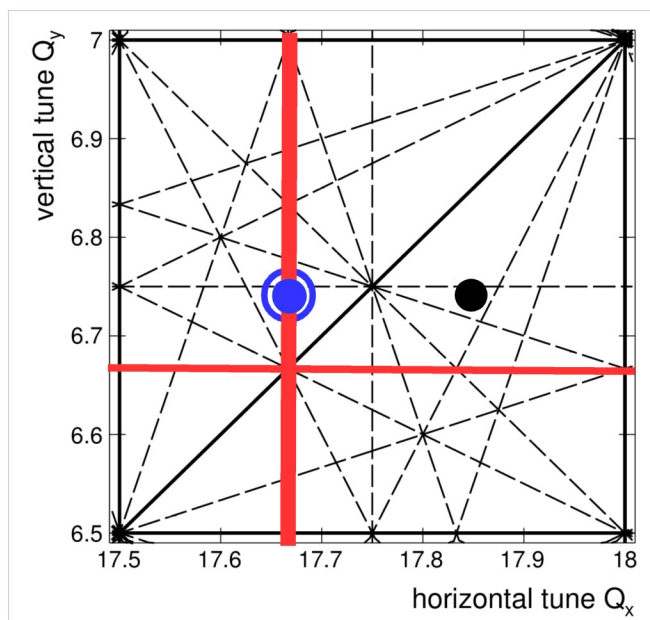


- Pseudo Single Bunch Scheme**, vertical kicking with a fast (50 ns) kicker, e^- bunch separation (ALS)



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

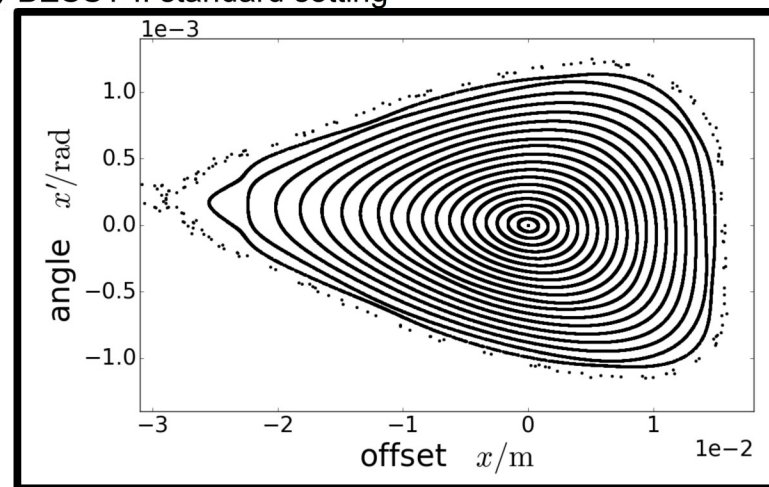


● BESSY II working point (17.85, 6.73)

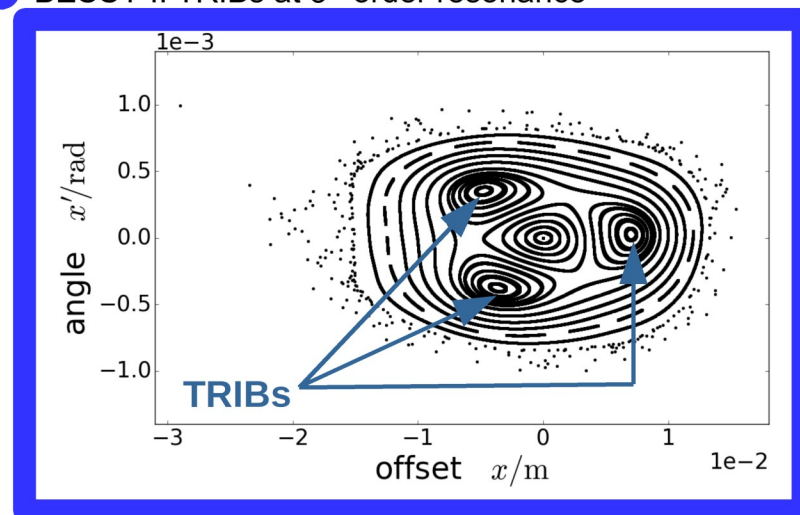
● BESSY II TRIBs at 3rd order (17.66, 6.73)

2nd stable fix point & orbit

● BESSY II standard setting

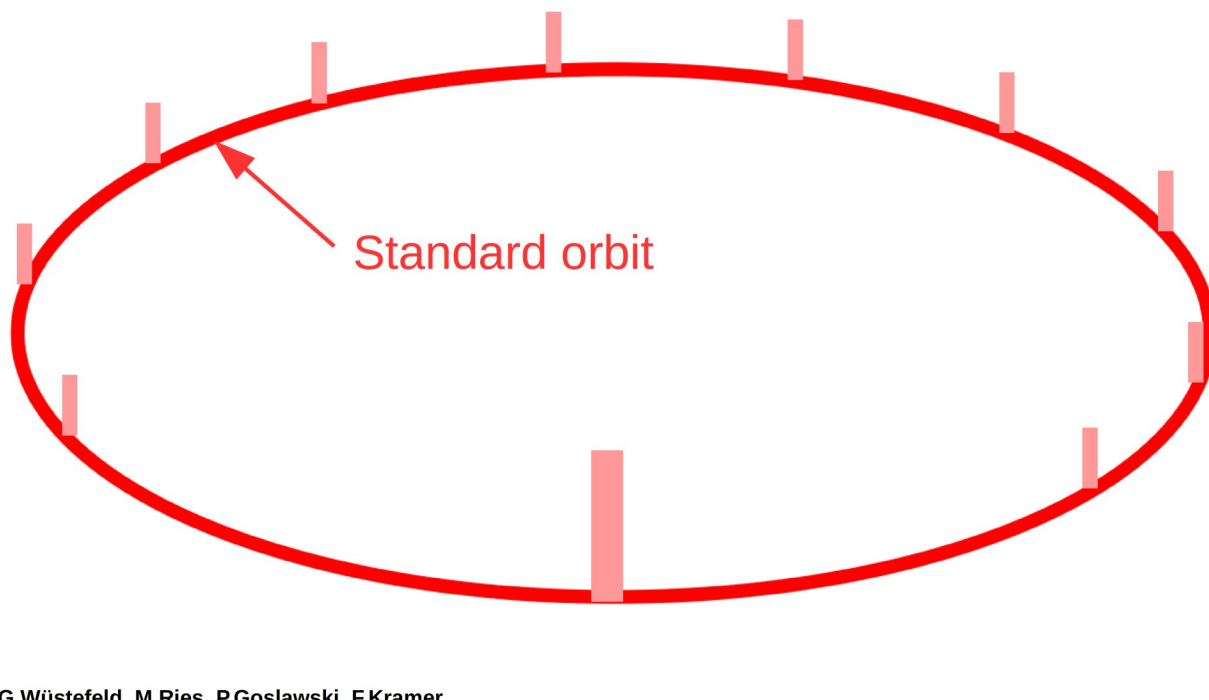


● BESSY II TRIBs at 3rd order resonance



Application: A new electron bunch separation scheme

2nd stable orbit with Transverse Resonance Island Buckets - TRIBs



Driving forces behind TRIBs – G.Wüstefeld, M.Ries, P.Goslawski, F.Kramer

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

P. Goslawski et al., "Resonance Island Experiments at BESSYII for User Applications"
Proceedings of IPAC2016, Busan, Korea, THPMR017

P. Goslawski et al., "Status of Transverse Resonance Island Buckets as Bunch Separation Scheme",
Proceedings of IPAC2017, Copenhagen, Denmark, WEPIK057

F. Kramer et al., "Characterisation of the second stable orbit generated by transverse resonance island buckets (TRIBs)", Proceedings of
IPAC2018, Vancouver, BC, Canada, TUPML052

**See talk of F. Kramer
at Student Retreat**

**Common Verbundforschungsprojekt
(Uni Mainz, Uni München):**

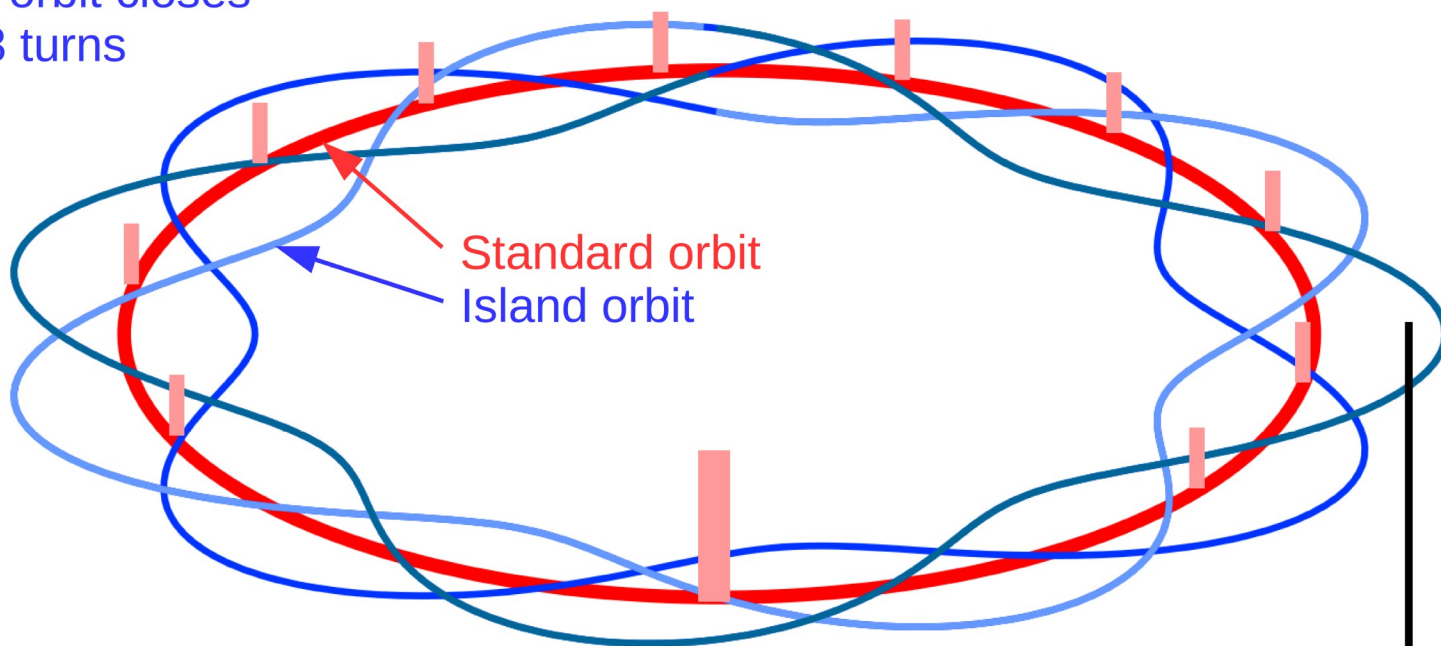
PhD student: TRIBs
as separation scheme



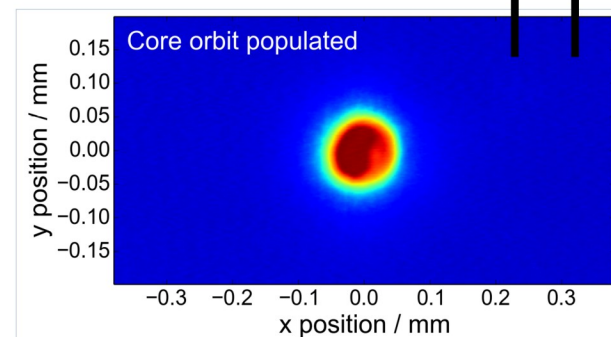
Application: A new electron bunch separation scheme

2nd stable orbit with Transverse Resonance Island Buckets - TRIBs

3rd order resonance
island orbit closes
after 3 turns



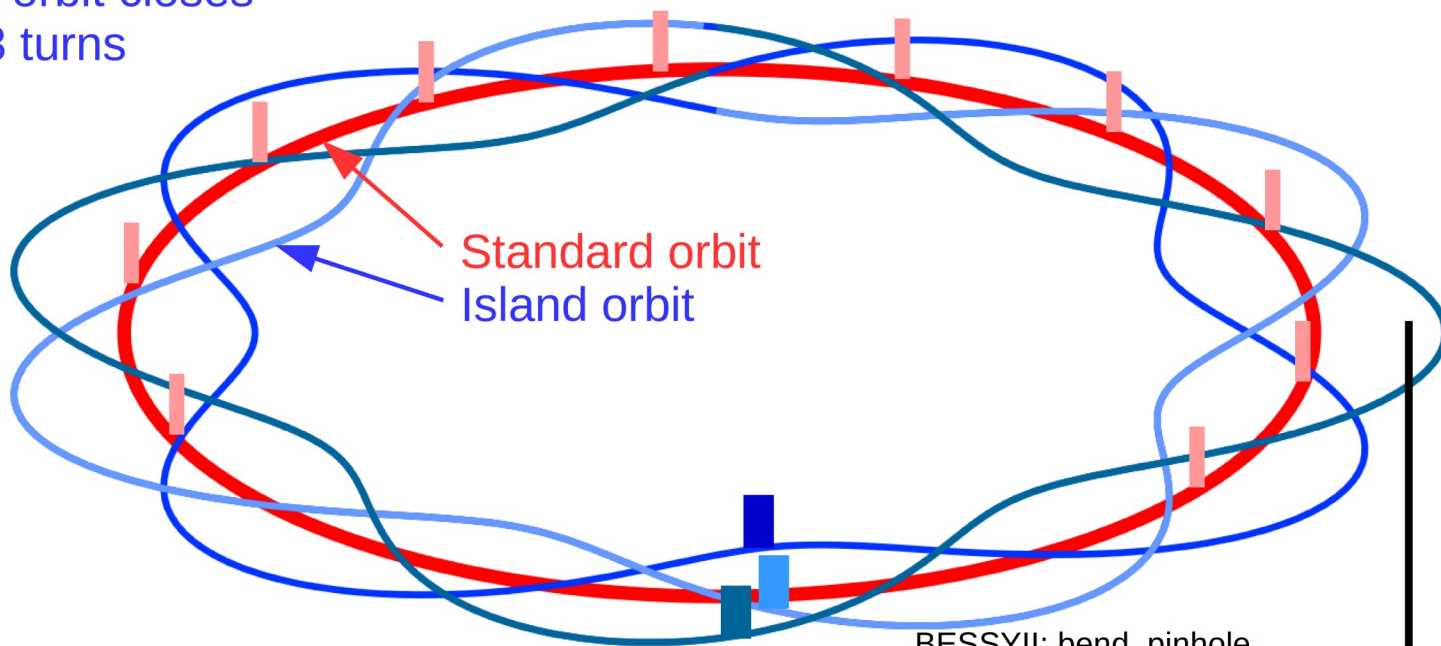
Two stable independent orbits
capable to store
two independent fill pattern



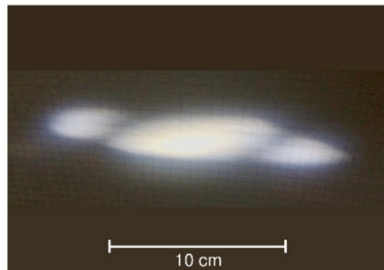
Application: A new electron bunch separation scheme

2nd stable orbit with **Transverse Resonance Island Buckets - TRIBs**

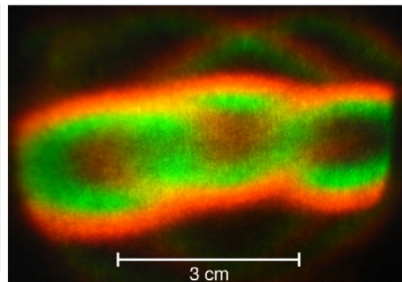
3rd order resonance
Island orbit closes
after 3 turns



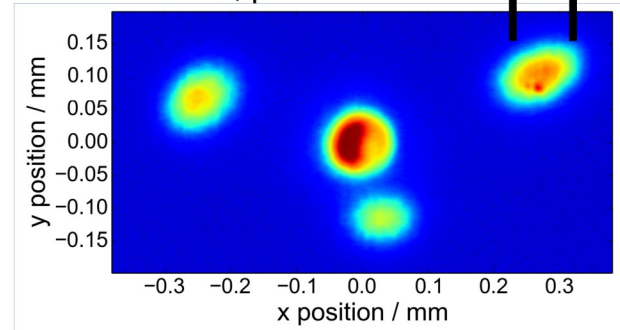
MLS: bend radiation



undulator radiation

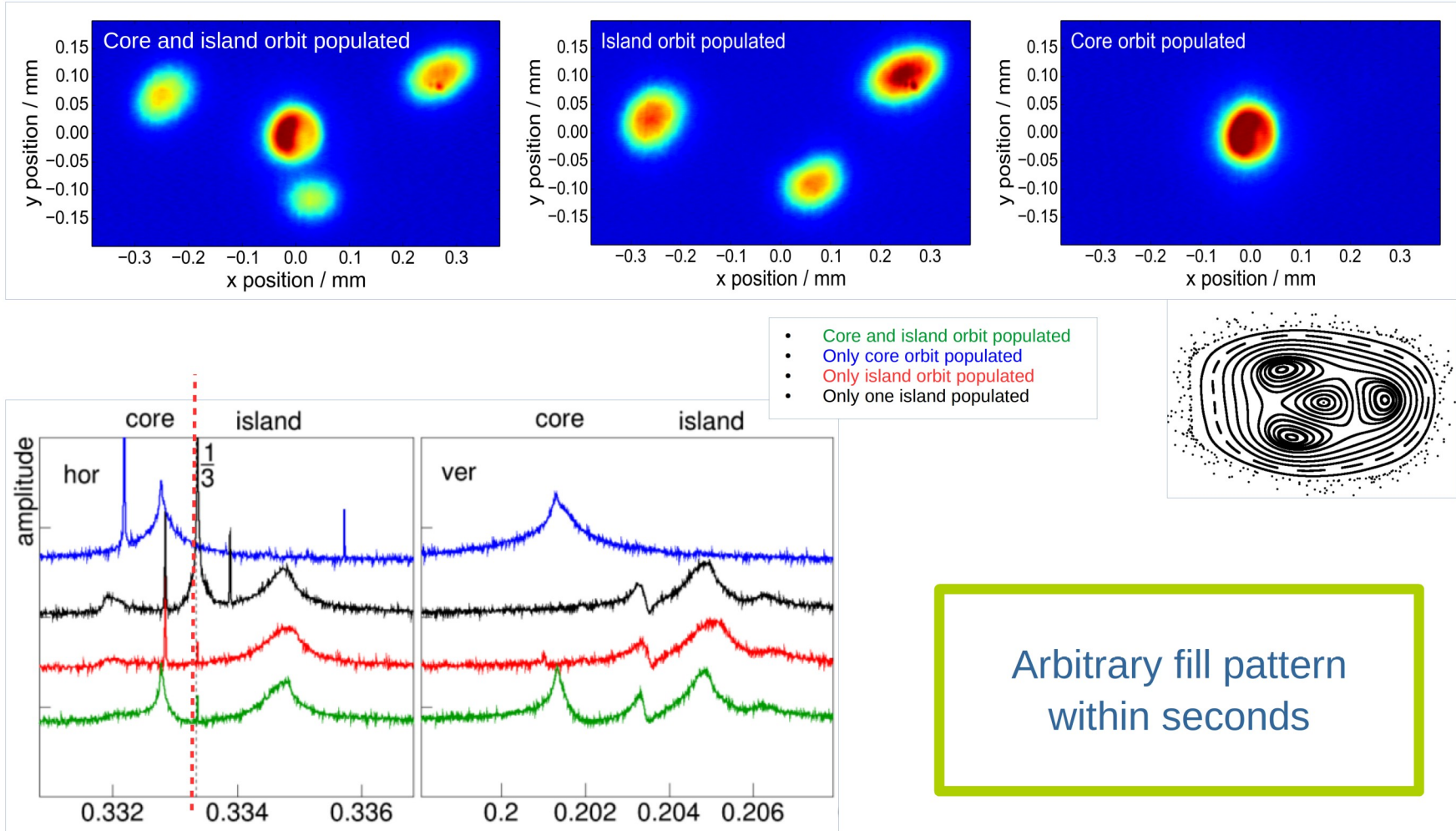


BESSYII: bend, pinhole



Fill pattern (or current) manipulation and tunes

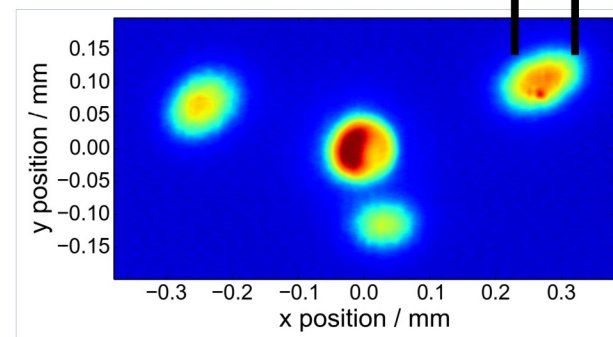
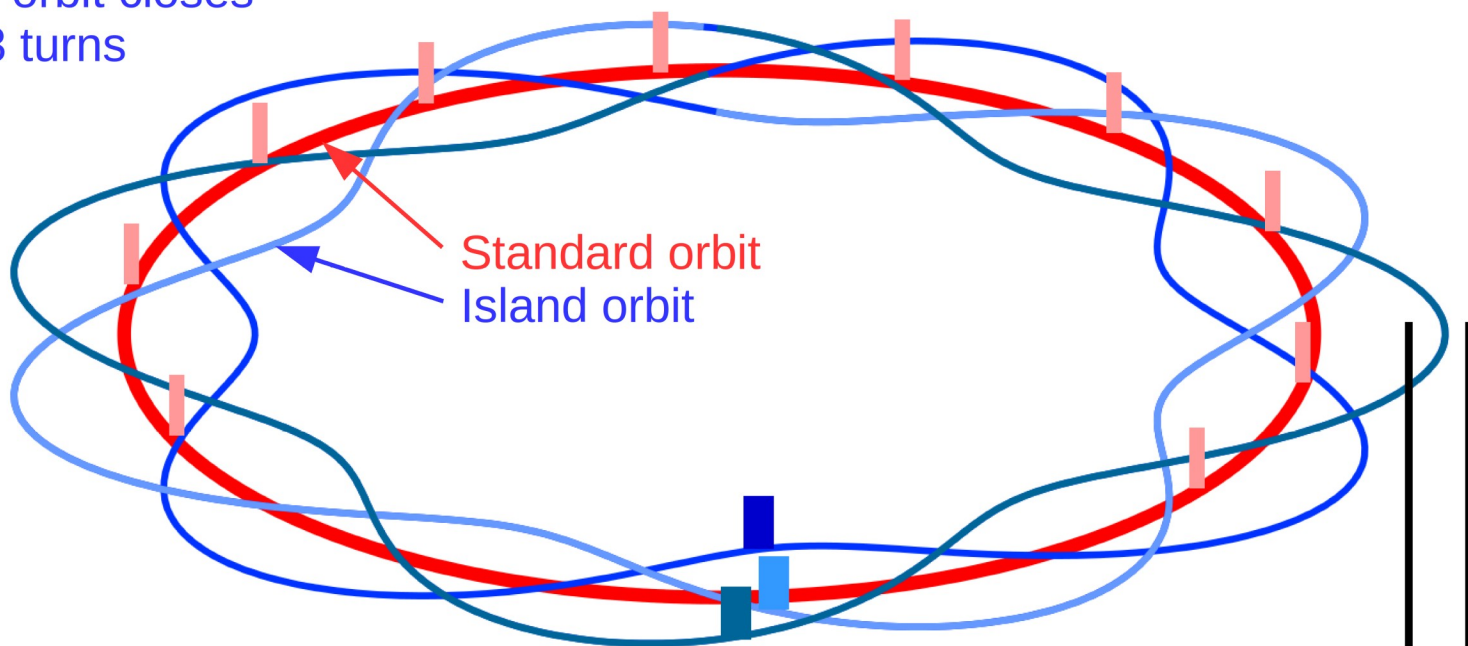
- Electrons can be shuffled between both orbits without losses



Application: A new electron bunch separation scheme

2nd stable orbit with **Transverse Resonance Island Buckets - TRIBs**

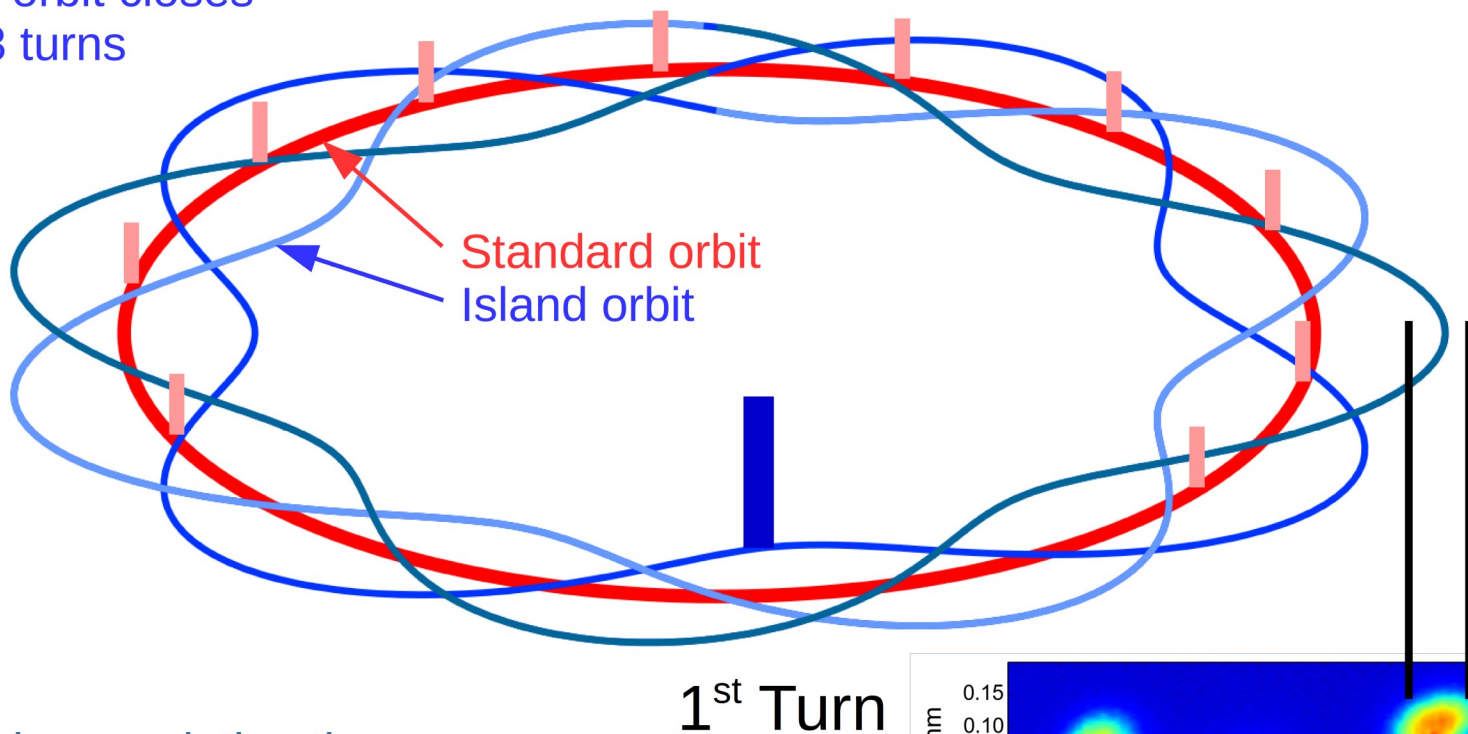
3rd order resonance
Island orbit closes
after 3 turns



Application: “elongate your ring” - increase revolution time

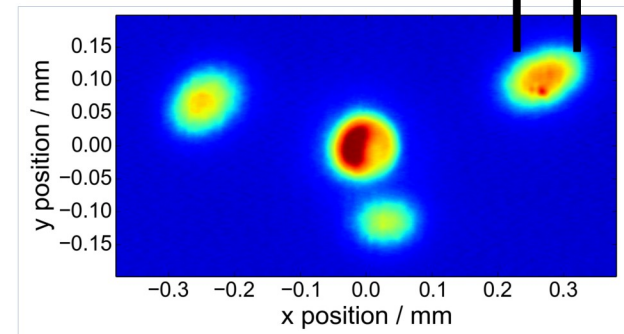
2nd stable orbit with Transverse Resonance Island Buckets - TRIBs

3rd order resonance
Island orbit closes
after 3 turns



Increasing revolution time

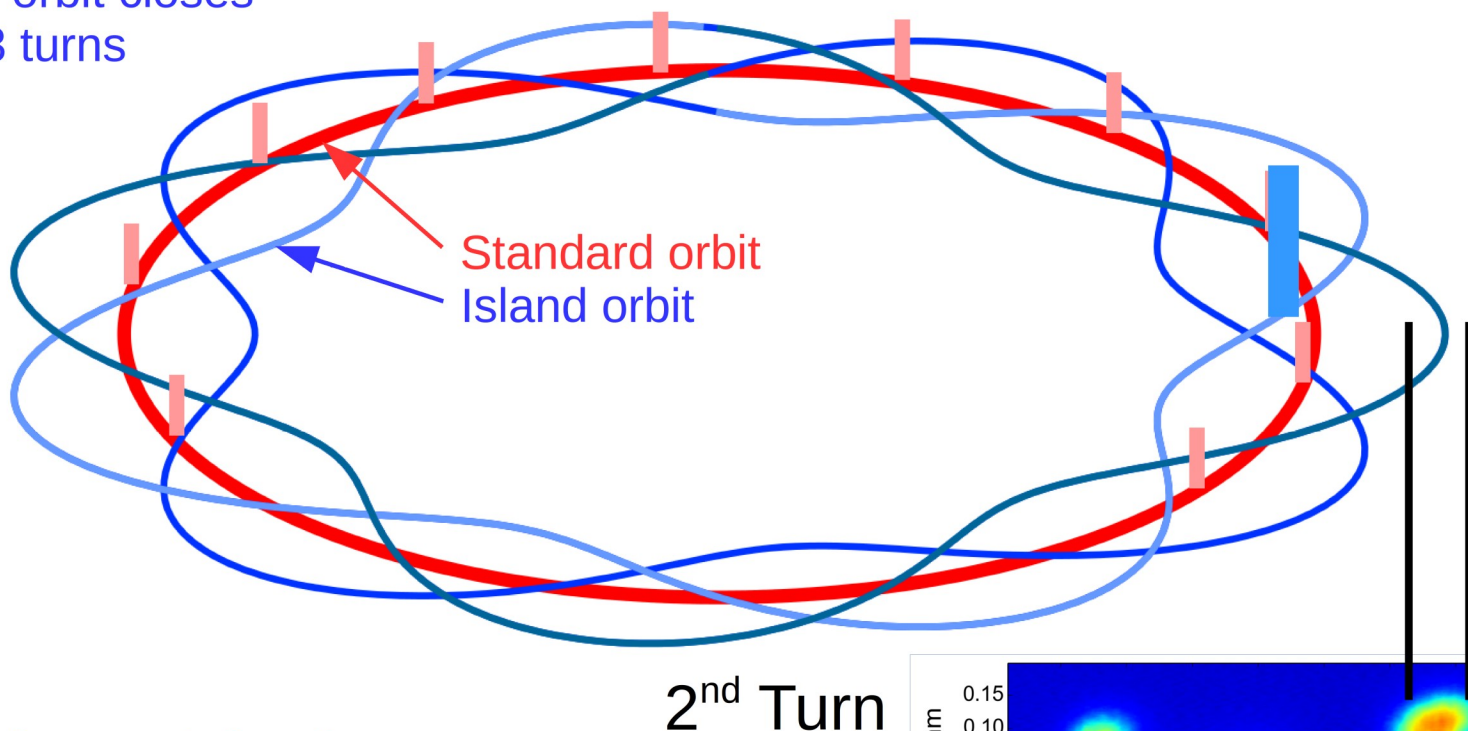
- By the factor = order of resonance



Application: “elongate your ring” - increase revolution time

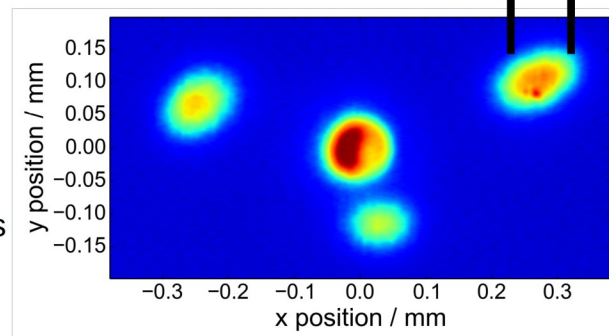
2nd stable orbit with Transverse Resonance Island Buckets - TRIBs

3rd order resonance
Island orbit closes
after 3 turns



Increasing revolution time

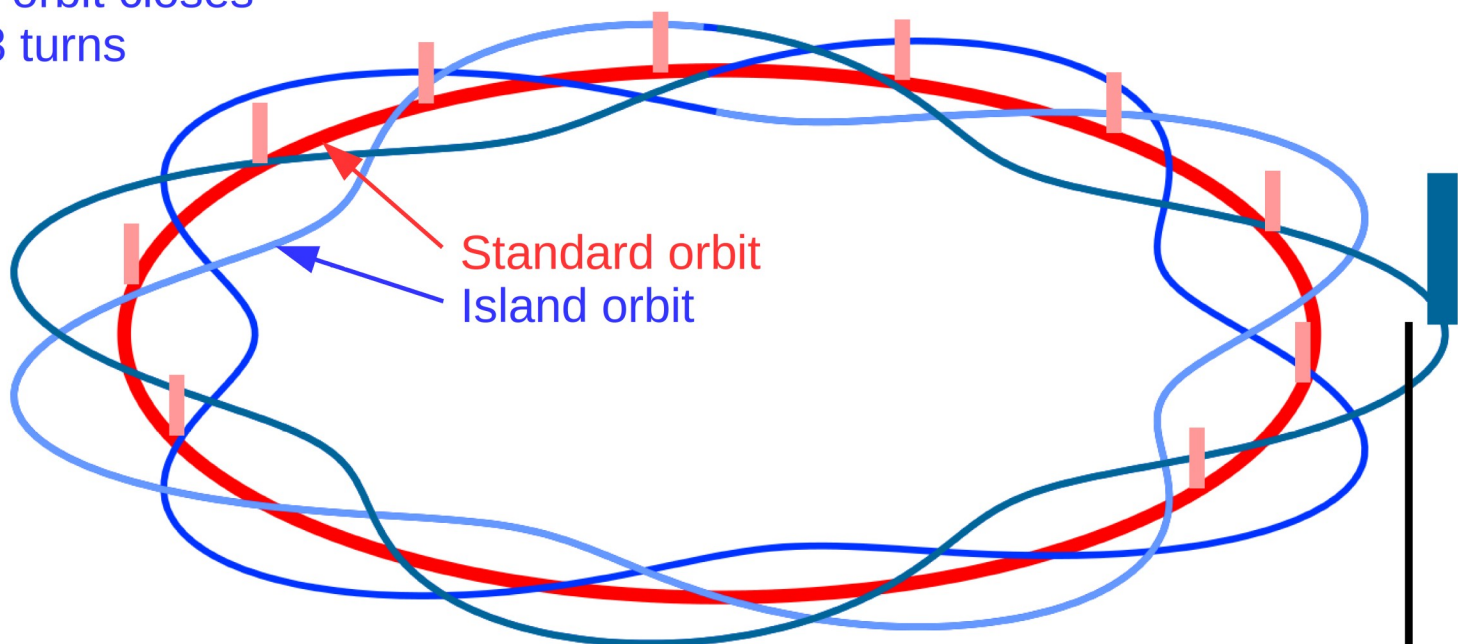
- By the factor = order of resonance
- Decrease repetition rate at small storage rings for TOF experiments



Application: “elongate your ring” - increase revolution time

2nd stable orbit with Transverse Resonance Island Buckets - TRIBs

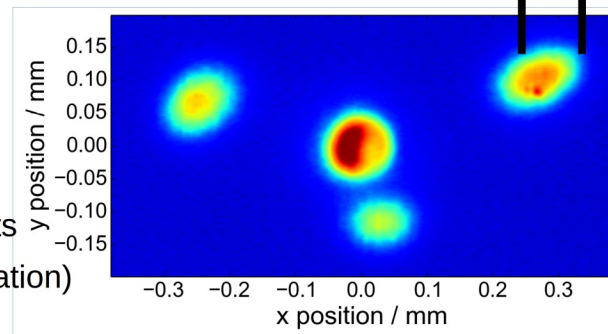
3rd order resonance
Island orbit closes
after 3 turns



3rd Turn

Increasing revolution time

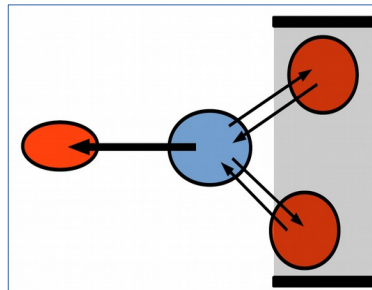
- By the factor = order of resonance
- Decrease repetition rate at small storage rings for TOF experiments
- First successful user experiment at the MLS (publication in preparation)



First successful user experiment at MLS (2015)

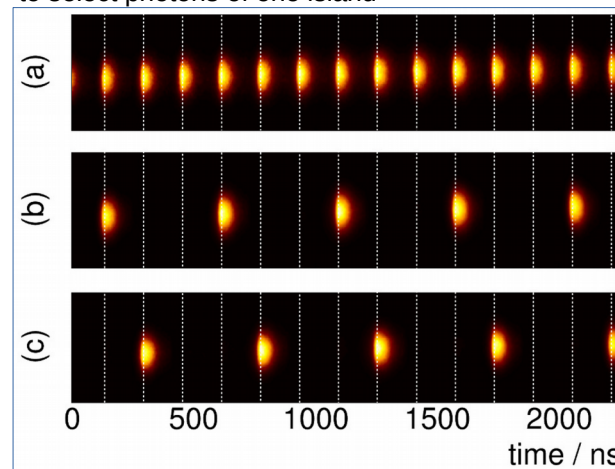
Current manipulation, sub-revolution frequency

- 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

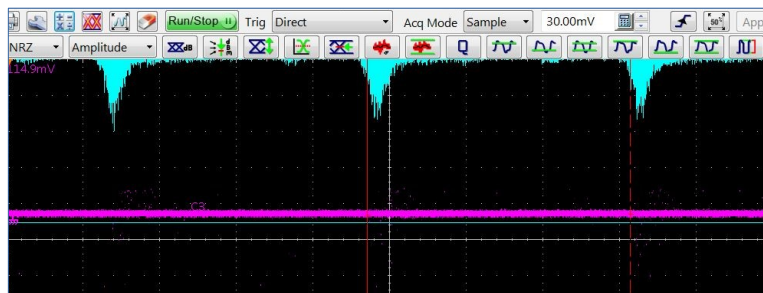
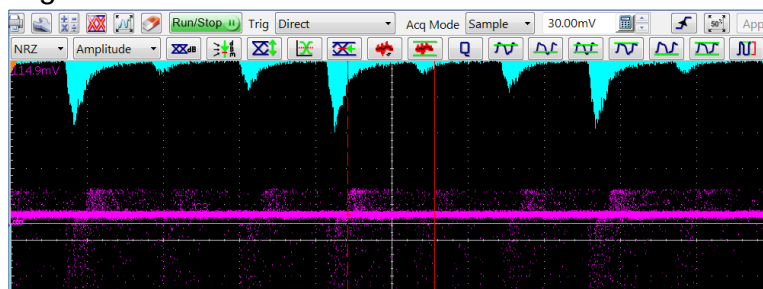


a) islands equally populated, kick every turn
b, c) only single island populated, pause-pause-kick
kick every 3rd turn

Streak camera with aperture
to select photons of one island



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 frequency 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

Proof of principle experiments

- Island operation compatible with
 - High current operation (300 mA)
 - IDs: moving undulator gaps and SC devices (7T MPW)

Since 2015



- **Separation - good enough?**

Electron separation --> Photon pulse separation?

- Beam parameters: orbit stability, emittance, ...
- Align island orbit on bend/ID beamline
- Purity, Diffusion rates, SNR
- Usable at all beamlines at the same time ?
- Impact of radiation from island orbit on standard orbit?

Fall 2015 – 2016



- **Injection - TopUp operation possible?**

- Injection Efficiency (>90%) and Lifetime (>5h@300mA) ?
- Difference between new working point (17.66) and old one (17.84)? (synchrotron source points from standard orbit)
- Impact of radiation from island orbit on standard orbit?

Fall 2016 – 2017



User test week
in February 2018

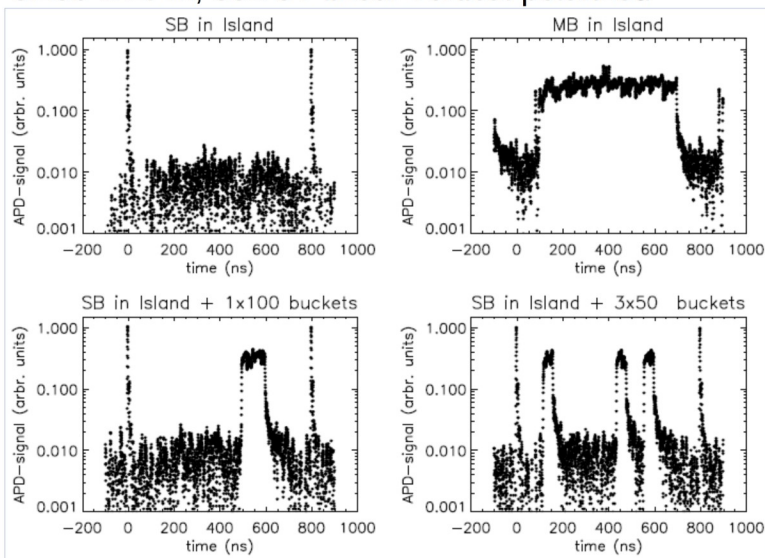
Common experiments with beam line scientists and in-house users

K.Holldack, F.Kronast, R.Ovsyannikov, E.Schierle, G.Schiwietz

Successful separation at bending magnet and undulator beam lines

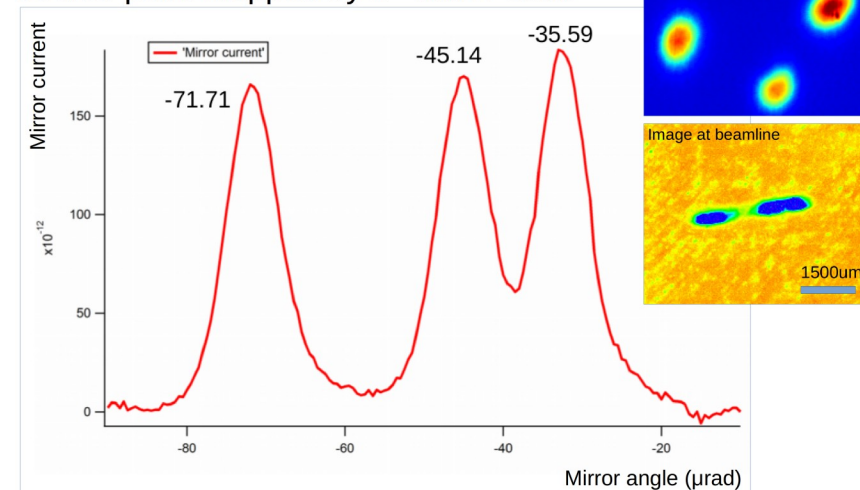
4 ID beam lines (**UE56-1**, **UE112**, UE49, UE46)

UE56-1 ZPM, 831 eV linear vertical polarized

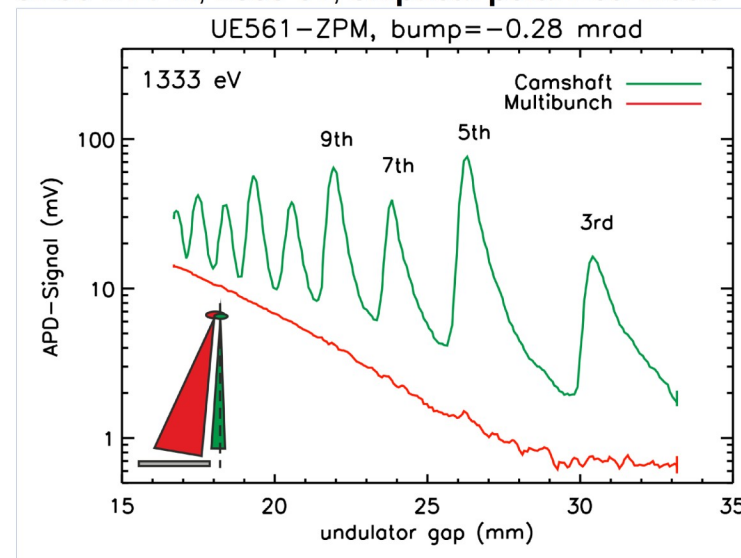


Bending magnet beamline (PM4)

Source point mapped by 1st mirror scan

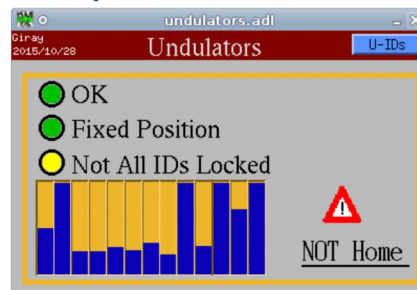


UE56-1 ZPM, 1333 eV, **elliptical polarized mode**

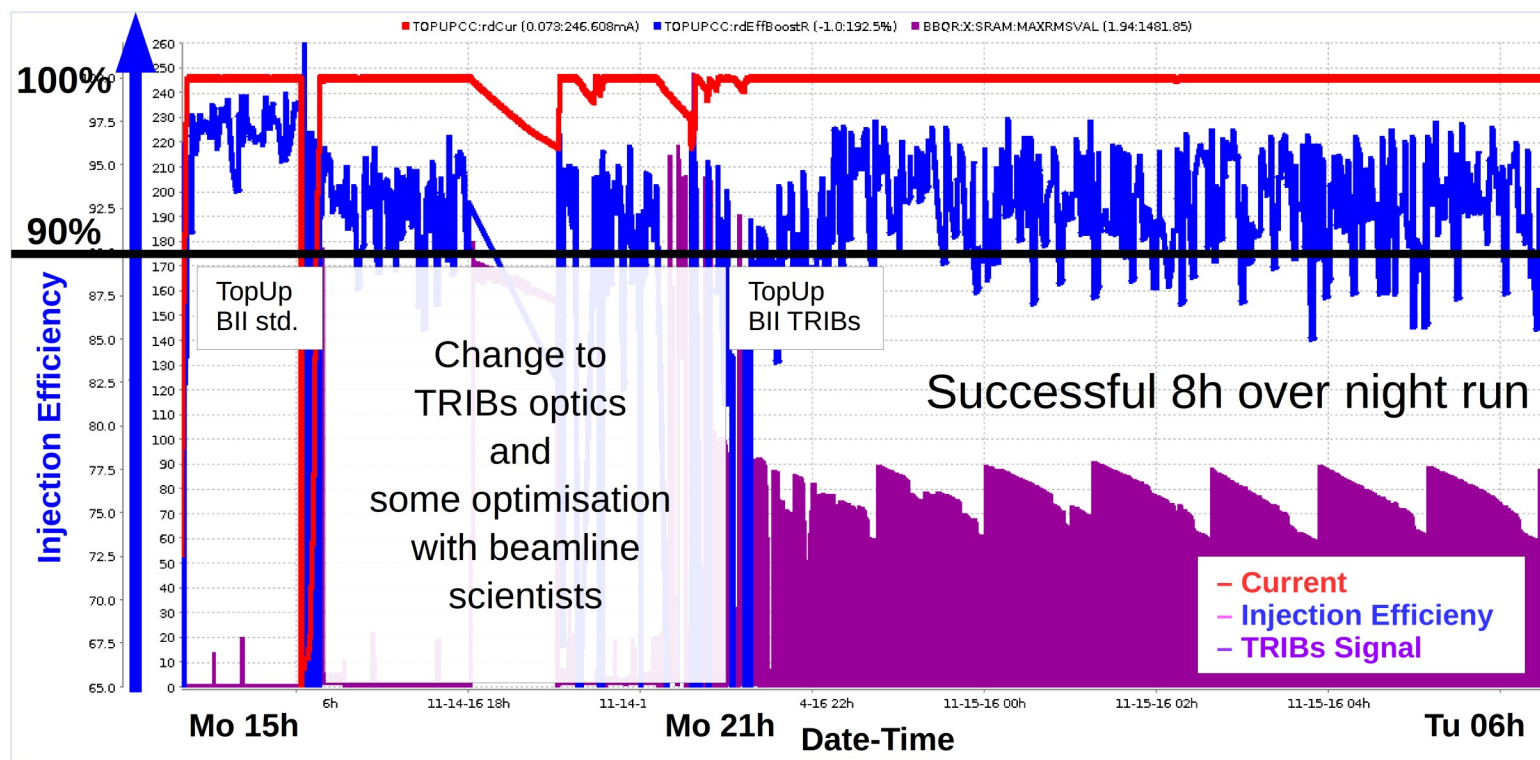


TopUp injection conditions for user operation

- Average injection efficiency > 90 %
- Shot by shot injection efficiency > 60 %
- Lifetime > 5 h @ 300 mA
- Stable user conditions over night !!



TRIBs feasible with
TopUp injection and
many closed IDs



TRIBs move towards realistic User Operation

- Verify if beam quality necessary for realistic user operation mode is reached in terms of
 - electron orbit, i.e., photon signal stability
 - simultaneous use of multiple IDs
 - injection efficiency and lifetime, i.e., TopUp conditions
- Verify that multibunch signal from main orbit is not disturbed by the island orbit signal
- Increase accessibility of the island orbit at most beamlines
- Daily schedule:
 - 07 – 10h: Storing ring optimisation
 - 10 – 15h: **Common experiments**
 - 15 – 18h: Restoring TRIBs for
 - 18 – 07h: **TRIBs User Run**

Availability	
availability increasing	
current week	calendar week 08
99.78 %	# outages 1
last week availability 98.37 %	MTBF 92.00 h
	MTTR 0.21 h
current year	# perfect weeks 1
99.28 %	# outages 10
	MTBF 67.4 h

- 11 Feedbacks so far under evaluation !

Open beam shutters / beamlines

20.02.2018 Tuesday 18:00

22/39

Status BESSY II		Overview	IDs	Beamshutter	Beamos
Beamshutters unlocked / Beam available					
● DIP 1.1 / EUV	23.8 eV	● UE49 / PGM-1	707.2 eV	UE49IT4R	
● DIP 1.2 / KMC1		● DIP 1.2 / PM4 OPTIC	75.0 eV	UE52ID5R	23.75 mm
● 7T WLS / -40mrad / BESSY	W7IT1R	● UE52	PGM1	600.0 eV	UE52ID5R
● 7T WLS / 0mrad / BAM		● DIP 1.1 / PM-1			27.24 mm
● DIP 1.2 / HE-SGM		● DIP 2.1 / KMC 2			
● DIP 2.1 / IRIS		● UE46	PGM1	901.5 eV	UE46IT5R
● U125/2	10m-NIM	● DIP 1.2 / fs-laser			26.80 mm
● DIP 1.2 / 5m NIM-2	21.7 eV	● UE56/1 PGM1	323.6 eV	UE56ID6R	40.65 mm
● 7T MPW / -12mrad	W7IT2R	● DIP 1.1 / PM-3	700.0 eV		99.99 mm
● 7T MPW / +1°		● DIP 2.1 / THz	THz-Signal -0.0 Volts	U139ID6R	
● DIP 1.2 / ISIS					
● UE56/2 PGM1 PGM2	200.0 eV	● UE48 / EMIL		UE48IT6R	92.93 mm
● DIP 1.1 / PM-2	770.0 eV	● DIP 1.2 / 3m-NIM-1		UE112ID7R	68.91 mm
● U41		● UE112	PGM1 PGM2	59.8 eV	UE112ID7R
● DIP 1.1 / LIGA		● DIP 2.1 / KMC-3			
● DIP 1.2 / PTB		● 7T WLS / -40mrad		W7IT7R	6.80 T
● U49/1 / PTB		● 7T WLS / +1°			
● DIP 1.1 / DWL PTB		● U49-2	PGM1 PGM2	554.9 eV	U49ID8R
● DIP 1.2 / KMC DWL PTB		● DIP 1.2 / TGM-7			99.99 mm
● DIP 2.1 / SX-700 PTB		● DIP 1.1 / DR-PGM	180.0 eV		

23.02. 2018 Friday 13:00

20/39

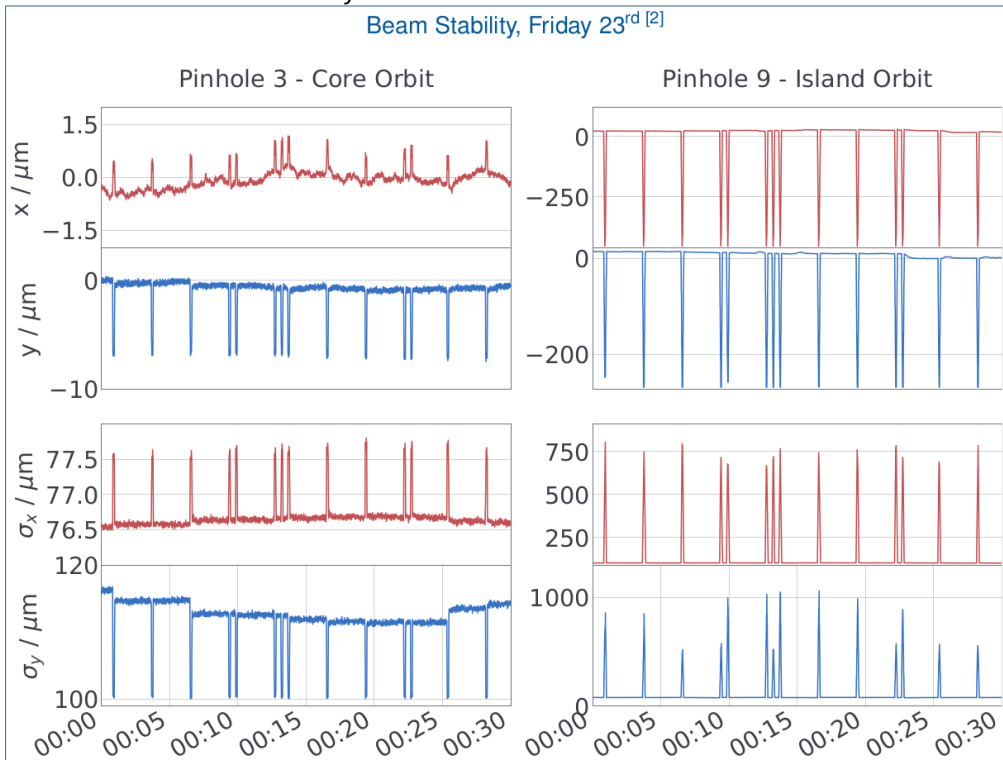
Status BESSY II		Overview	IDs	Beamshutter	Beamos
Beamshutters unlocked / Beam available					
● DIP 1.1 / EUV	14.0 eV	● UE49 / PGM-1	700.0 eV	UE49IT4R	
● DIP 1.2 / KMC1		● DIP 1.2 / PM4 OPTIC	75.0 eV	UE52ID5R	26.24 mm
● 7T WLS / -40mrad / BESSY	W7IT1R	● UE52	PGM1	200.0 eV	UE52ID5R
● 7T WLS / 0mrad / BAM		● DIP 1.1 / PM-1			27.20 mm
● DIP 1.2 / HE-SGM		● DIP 2.1 / KMC 2			
● DIP 2.1 / IRIS		● UE46	PGM1	931.5 eV	UE46IT5R
● U125/2	10m-NIM	● DIP 1.2 / fs-laser			24.35 mm
● DIP 1.2 / 5m NIM-2	18.0 eV	● UE56/1 PGM1	460.0 eV	UE56ID6R	46.20 mm
● 7T MPW / -12mrad	W7IT2R	● DIP 1.1 / PM-3	700.0 eV		100.00 mm
● 7T MPW / +1°		● DIP 2.1 / THz	THz-Signal 0.0 Volts	U139ID6R	
● DIP 1.2 / ISIS					
● UE56/2 PGM1 PGM2	200.0 eV	● UE48 / EMIL		UE48IT6R	35.99 mm
● DIP 1.1 / PM-2	770.0 eV	● DIP 1.2 / 3m-NIM-1		UE112ID7R	60.34 mm
● U41		● UE112	PGM1 PGM2	40.0 eV	UE112ID7R
● DIP 1.1 / LIGA		● DIP 2.1 / KMC-3			
● DIP 1.2 / PTB		● 7T WLS / -40mrad		W7IT7R	6.80 T
● U49/1 / PTB		● 7T WLS / +1°			
● DIP 1.1 / DWL PTB		● U49-2	PGM1 PGM2	550.0 eV	U49ID8R
● DIP 1.2 / KMC DWL PTB		● DIP 1.2 / TGM-7			23.52 mm
● DIP 2.1 / SX-700 PTB		● DIP 1.1 / DR-PGM	650.0 eV		

Challenges for better user operation

- 11 User feedbacks so far ... under evaluation!
- TopUp Injection... Injection disturbances
- Transparent orbit bumps for IDs
- Slicing, bending beamlines without focus

Source size and orbit stability

Beam Stability, Friday 23rd [2]



New quality, new options

- Operation and separation without gap, avoiding beamloading (especially for VSR)
- Fast switching of fill patterns, two different sources at one sample (x-ray optics)
- Two repetition rates at same time
- ... (injection, ...)

Stored current and Injection Efficiency



Proof-of-Principles Experiments done !

- **Separation scheme**, two stable orbits in one machine, 2nd lane, 2nd fillpattern (average brightness and timing)
- Established user operation at decaying machine with one ID (MLS), --> increasing revolution time
- Studies towards user operation in a 3rd generation light source, --> combine with TOPUP injection scheme, many IDs (BESSY II / VSR)



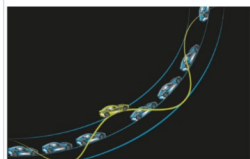
will provide long and short intense bunches simultaneously → pulse separation mandatory

Fall 2015 see news
HZB and lightsources.org



11.11.2015

BESSY II electron highway gets second lane

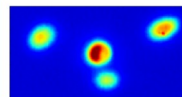


The particle accelerator team at Helmholtz-Zentrum Berlin (HZB) has demonstrated that BESSY II, the 3rd generation synchrotron radiation source in Berlin, can be operated with not just one, but two simultaneous electron paths. By precisely tuning the magnetic components, physicists can create an additional orbital path. Packets of electrons can travel along it and emit intense light pulses at the experiment stations. This could provide the user community with the option to select light pulses from either path as needed in their experiments. The newly developed orbital mode has already been stably implemented and initial tests at the experiment stations (beamlines) show promising results. HZB is the first to enter this new territory and at the same time has reached another milestone in its pioneering BESSY-VSR project.

Spring 2018 see news
HZB and lightsources.org

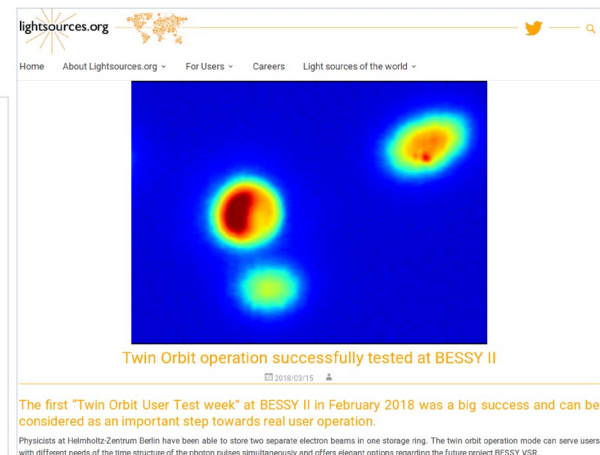
15.03.2018

Twin Orbit operation successfully tested at BESSY II

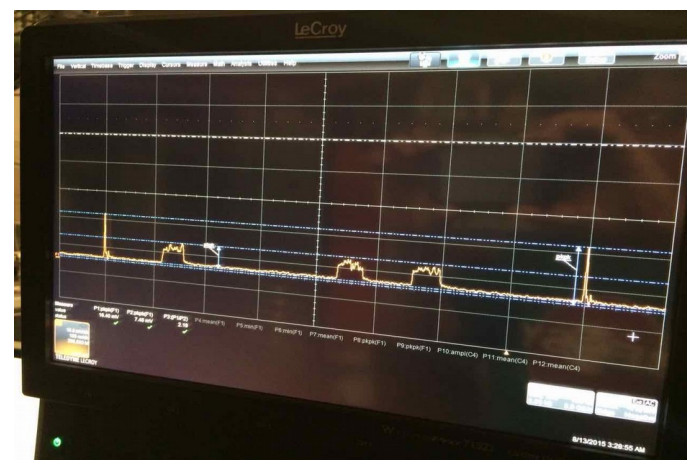
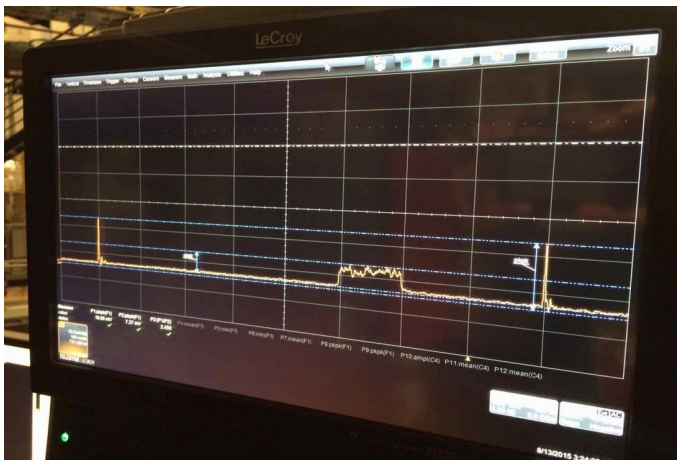
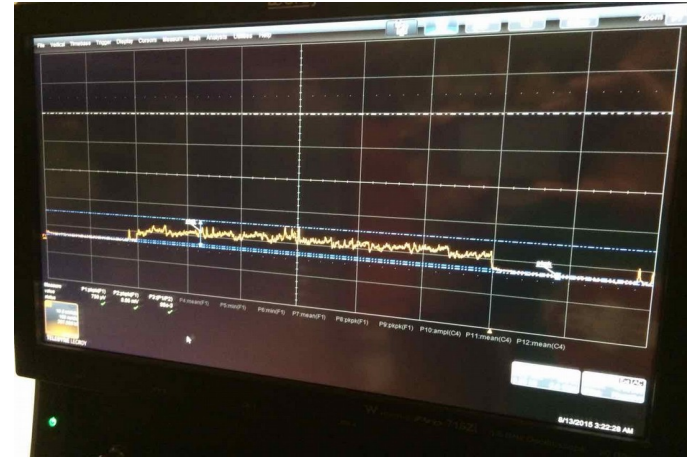
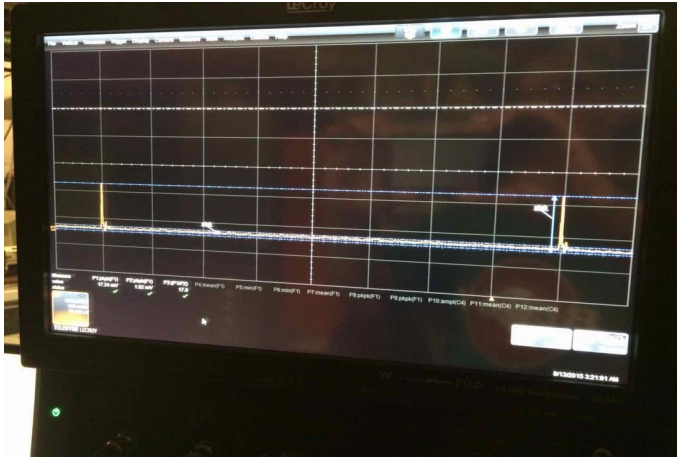


A synchrotron source point image of a bending magnet of the Twin Orbit modus. The second orbit closes after three revolution and is winding around the standard orbit at the center. Credit: HZB

The first "Twin Orbit User Test week" at BESSY II in February 2018 was a big success and can be considered as an important step towards real user operation. Physicists at Helmholtz-Zentrum Berlin have been able to store two separate electron beams in one storage ring. The twin orbit operation mode can serve users with different needs of the time structure of the photon pulses simultaneously and offers elegant options regarding the future project BESSY VSR.



Thank you for your attention



Thanks to all Colleagues at HZB and external users contributing to TRIBs

