First experimental results of operating beams split in horizontal phase space at BESSY II / MLS

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

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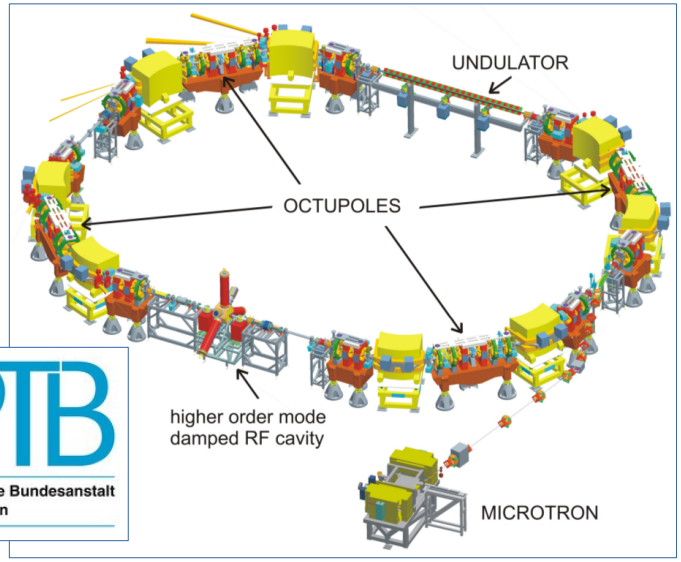
21th September 2017
NOCE2017, Arcidosso, Italy

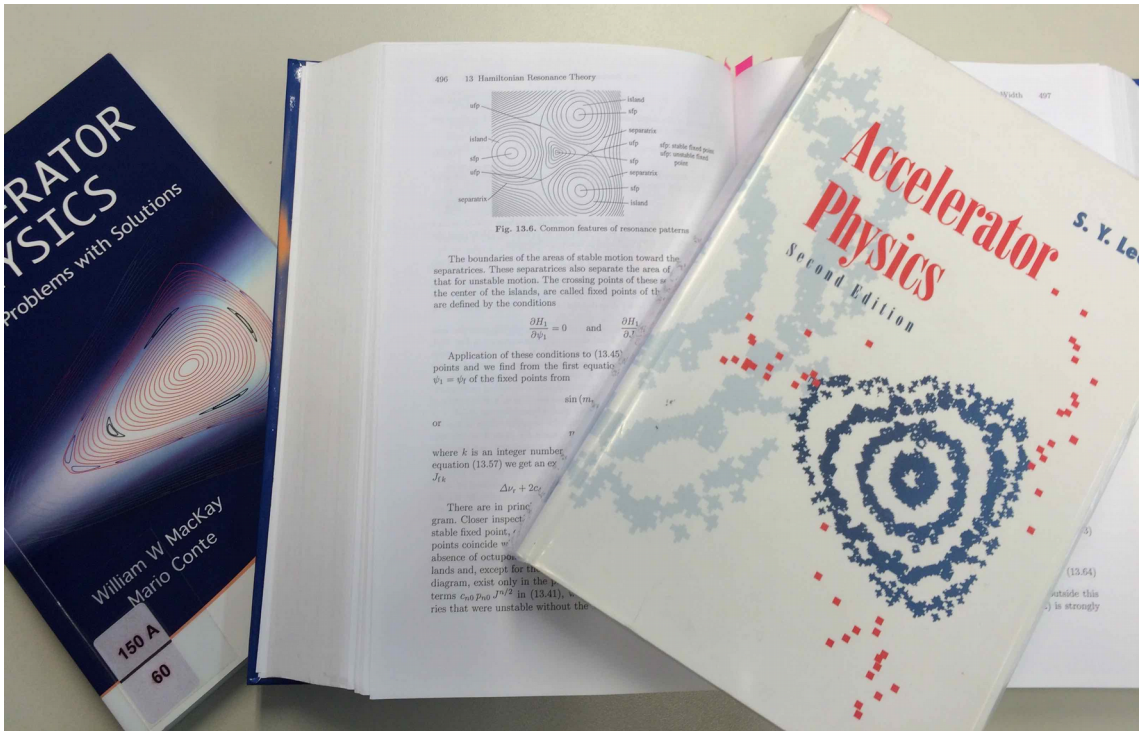
Overview

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



Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

TRIBs - Not new



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

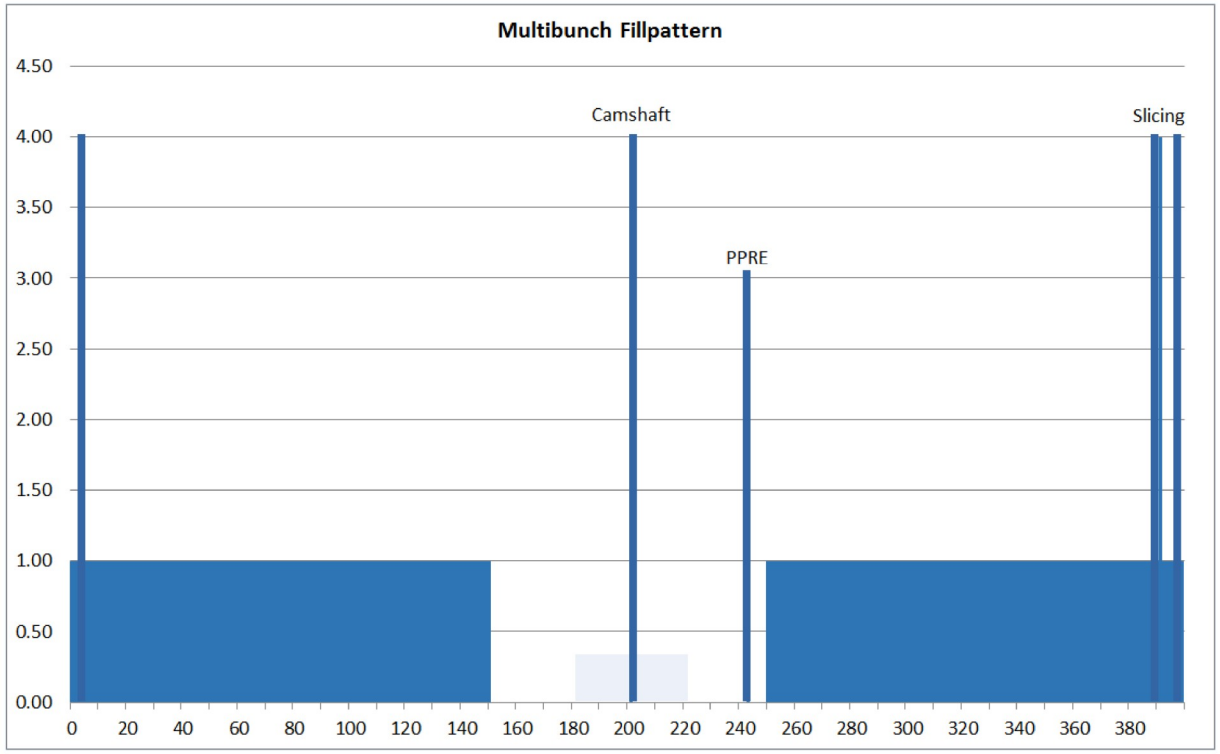
Application: Multiturn (slow) extraction

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

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

Motivation for TRIBs - Fillpattern at BESSY II / VSR

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



Hybrid Multibunch Fill

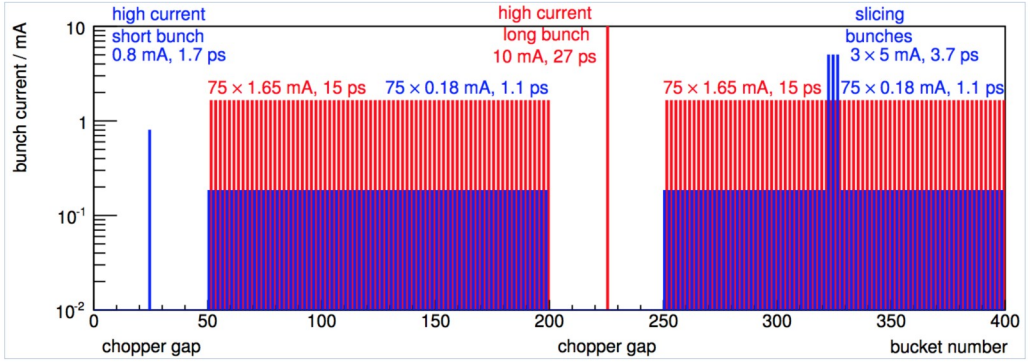
- MultiBunch train of 300 buckets
  -> Average brilliance
- SingleBunch in ion clearing gap
  -> Time resolved exp.
- Pulse Picking Resonant Excitation
  -> ARTOF (reduced intensity)
- Three Slicing bunches
  -> Ultra short X-Ray pulses (100 fs)

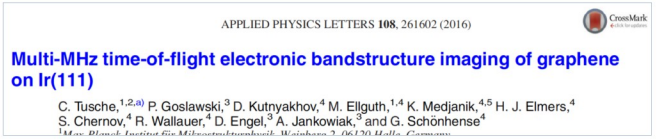
Rep.rate: 800ns, 1.25MHz
1x15mA

- Single Bunch Mode
  Few Bunch Mode

Rep.rate: 200ns, 5.0MHz
4x8=32mA

- Low alpha operation




APPLIED PHYSICS LETTERS 108, 261602 (2016)

Multi-MHz time-of-flight electronic bandstructure imaging of graphene on Ir(111)

C. Tusche,[1,2,a)] P. Goslawski,[3] D. Kutnyakhov,[4] M. Ellguth,[1,4] K. Medjanik,[4,5] H. J. Elmers,[4] S. Chernov,[4] R. Wallauer,[4] D. Engel,[3] A. Jankowiak,[3] and G. Schönhense[4]

Future BESSY VSR fill pattern

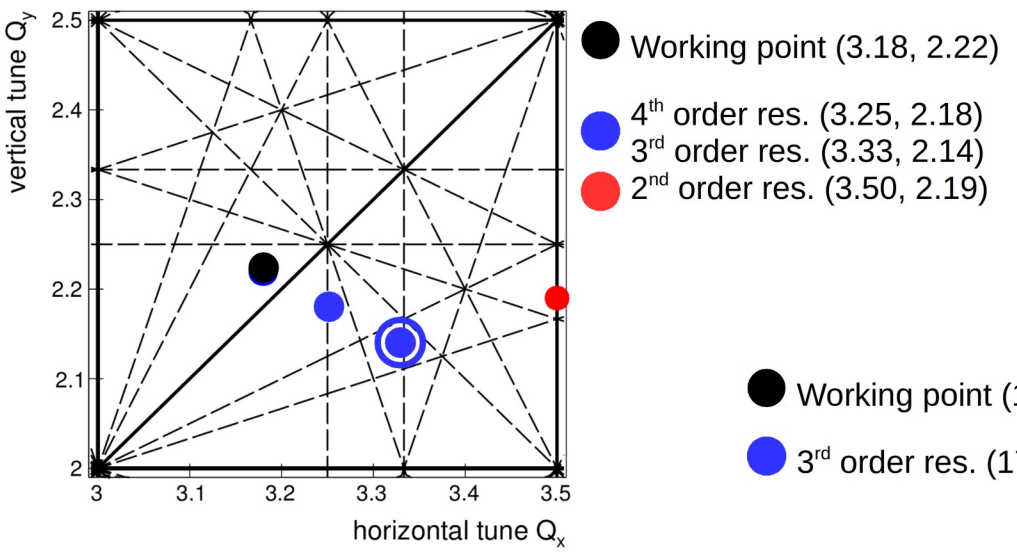
Common Verbundforschungsprojekt (Uni Mainz, Uni München):

PhD student: TRIBs as separation scheme

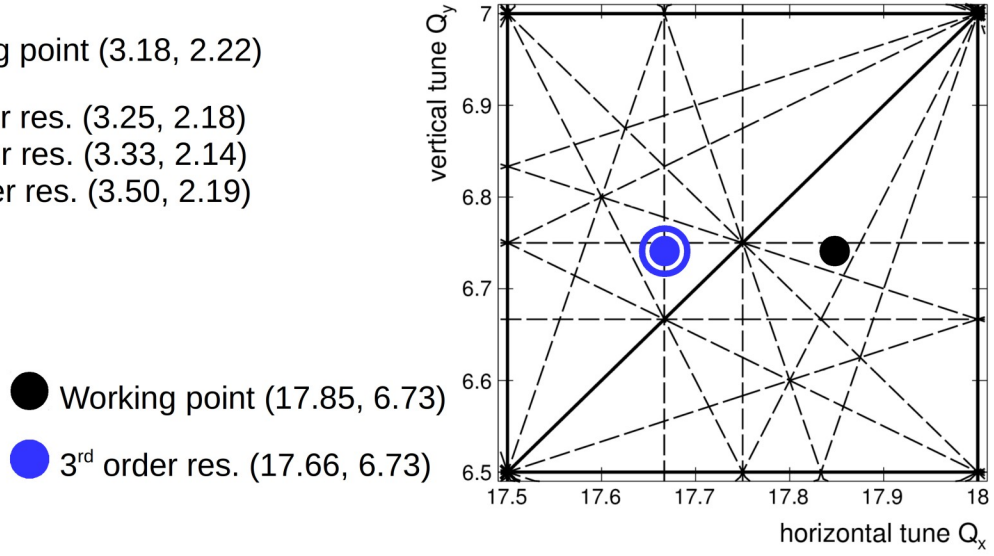
Bundesministerium für Bildung und Forschung

TRIBs (Resonances) at BESSY II and MLS

Island buckets at MLS



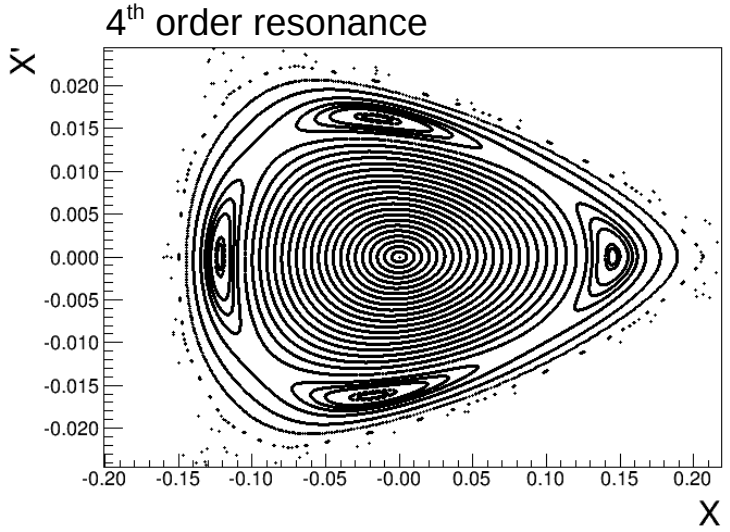
Island buckets at BESSY II



Operating machine close to horizontal resonance

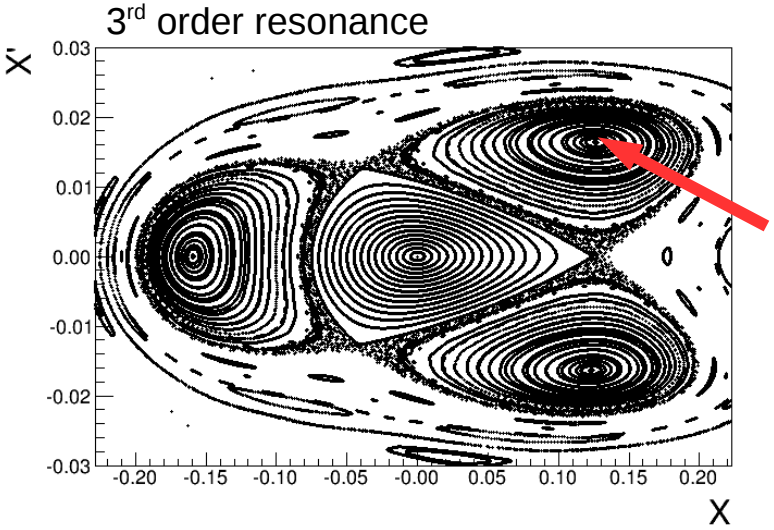
- Only small de-tuning needed to move close to resonance
- Minor impact on linear beam optics expected
- No big changes of beta function and dispersion

TRIBs - Additional Orbit

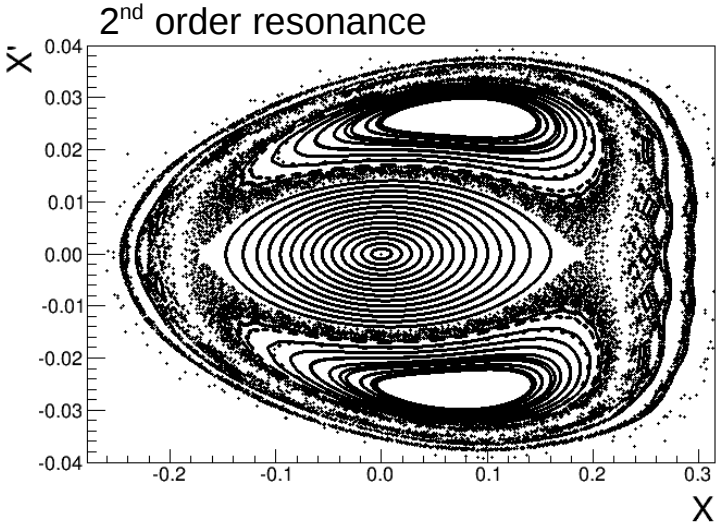


(x, x') phase space simulations

- Near resonance additional stable buckets
- Number of buckets = n, order of resonance
- 2nd stable orbit winding around the standard orbit closing after n revolutions

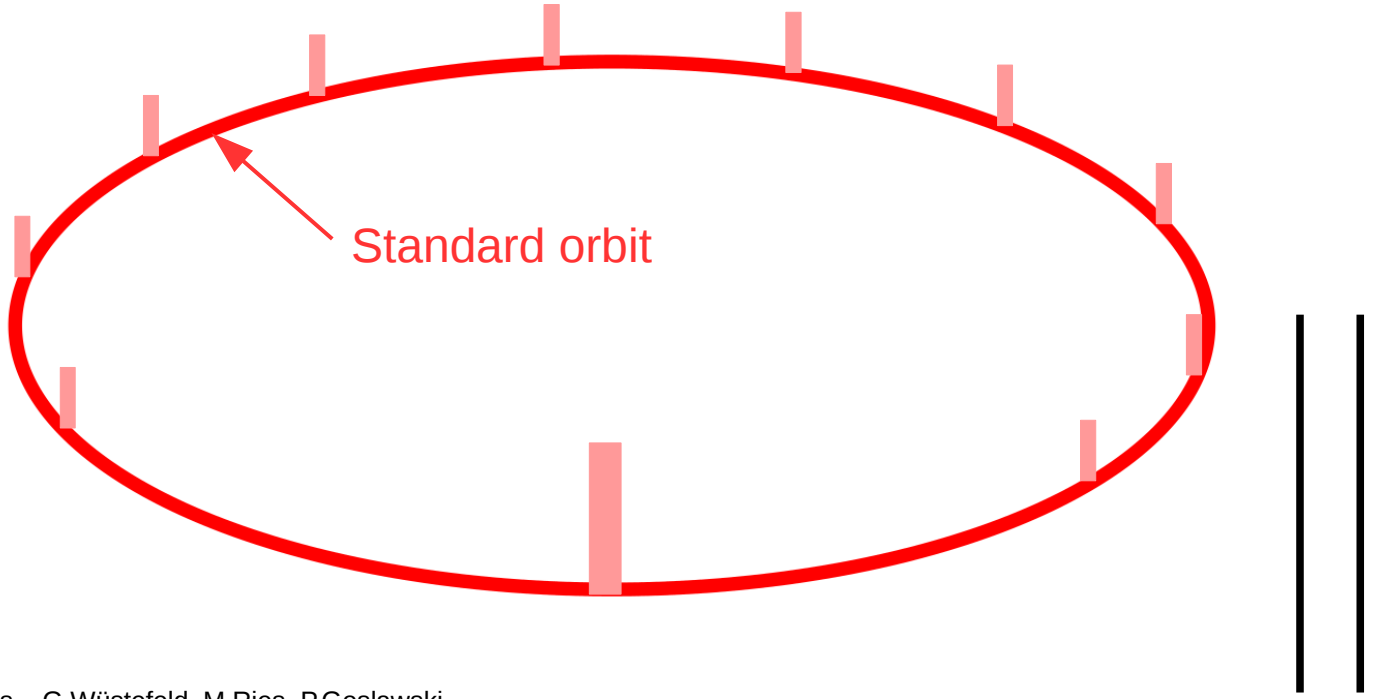


ISLAND Buckets



TRIBs - Additional Orbit

Separation scheme using transverse resonance island orbit



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

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

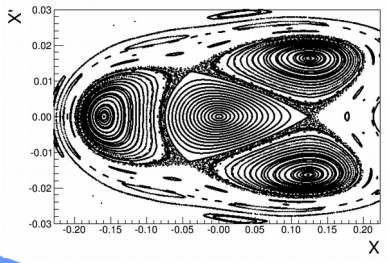
P. Goslawski et al., “Resonance Island Experiments at BESSYII for User Applications”
Proceedings of IPAC2016, Busan, Korea, THPMR017

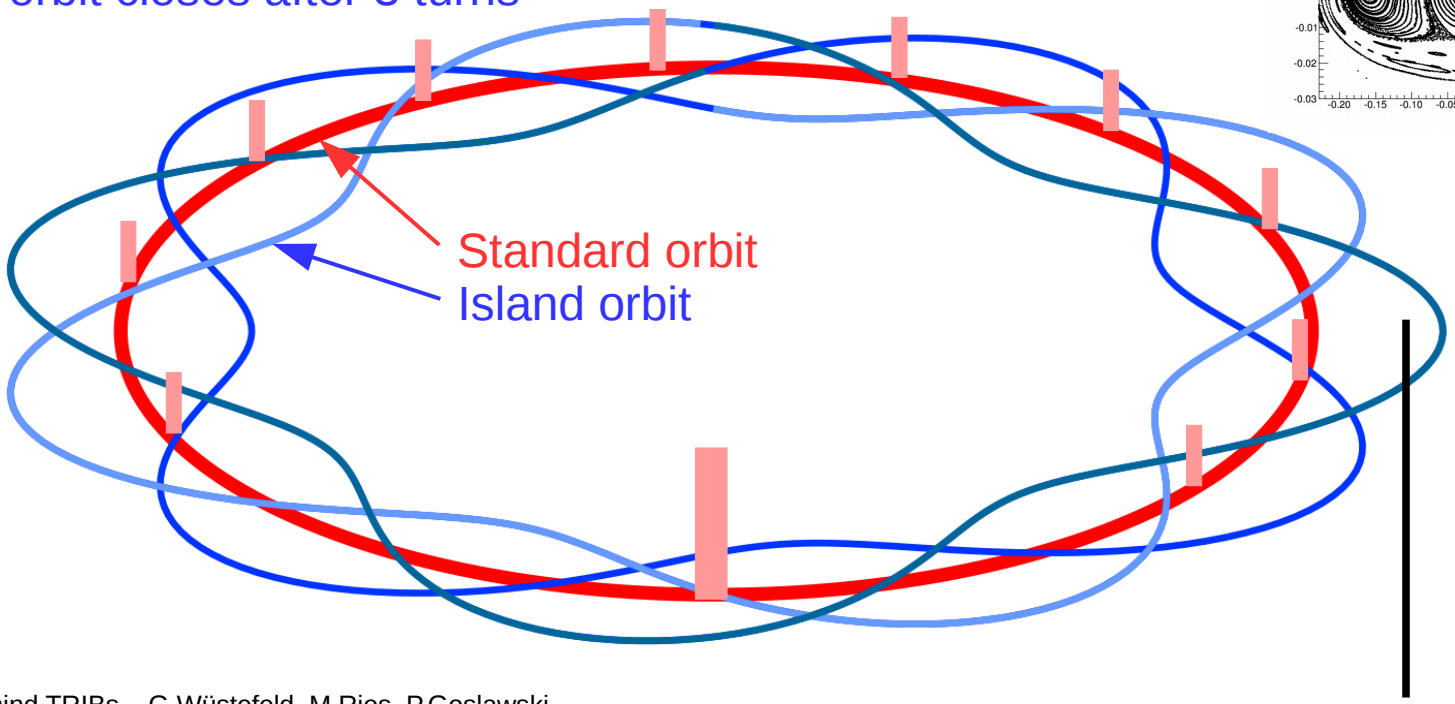
P. Goslawski et al., “Status of Transverse Resonance Island Buckets as Bunch Separation Scheme“, Proceedings of IPAC2017, Copenhagen, Denmark, WEPIK057

TRIBs - Additional Orbit

Separation scheme using transverse resonance island orbit

3rd order resonance
Island orbit closes after 3 turns





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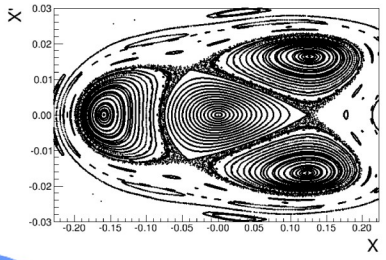
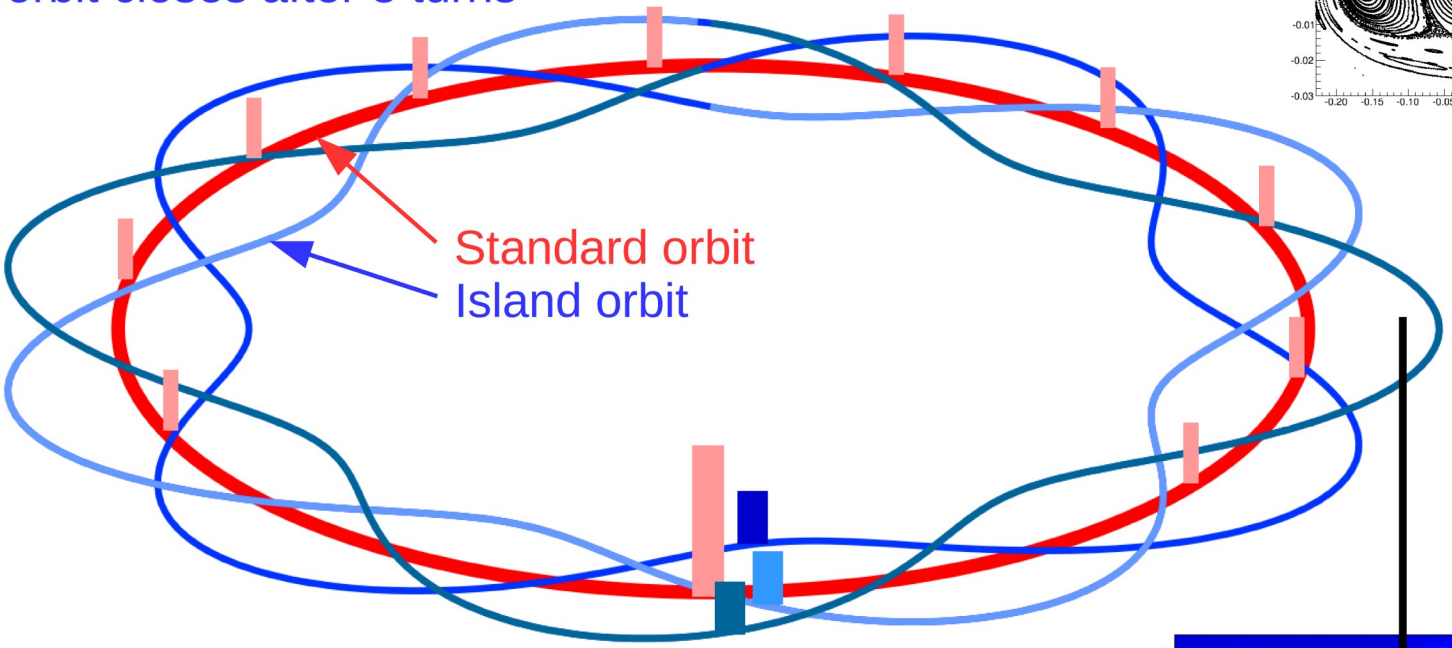




Beam separation at beamlines

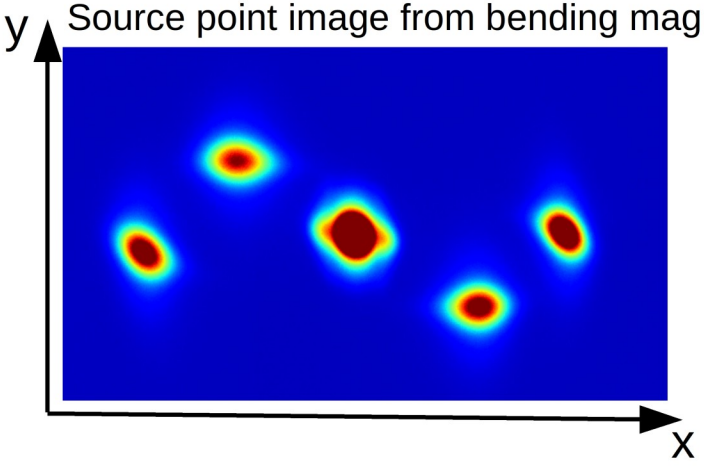
- Spectral monochromators use vertical plane as dispersion plane, so a horizontal separation would be favourable
- No big changes at beamlines necessary (in contrast to vertical kicking)

TRIBs at MLS and BESSY II

M. Ries et al., Proceedings of IPAC2015, Richmond, VA, USA, MOPWA021

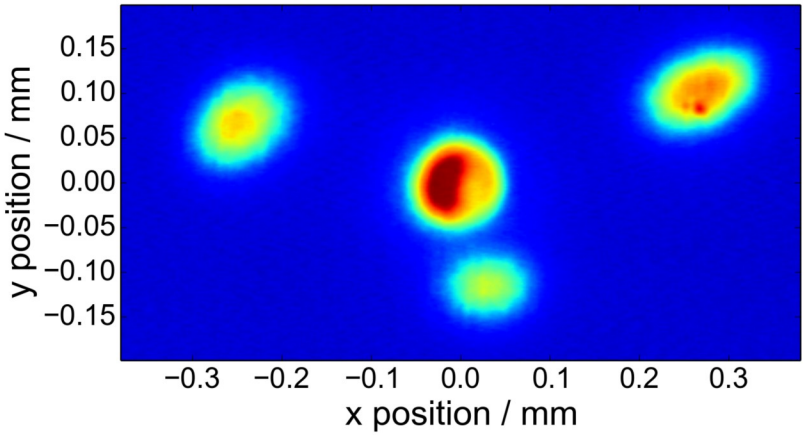
Island buckets at MLS

4th order resonance
Source point image from bending magnet



Island buckets at BESSY II

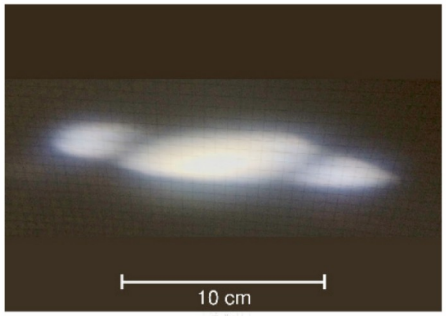
3rd order resonance
Source point image from bending magnet



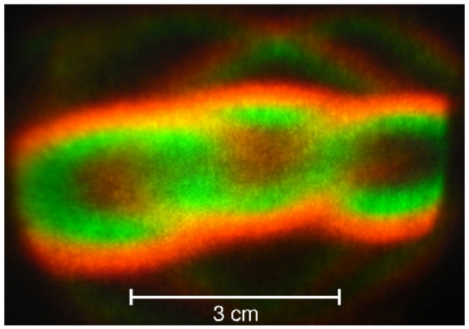
Island buckets at photon beamlines

3rd order resonance

Bending magnet beamline



Undulator beamline



How to generate islands

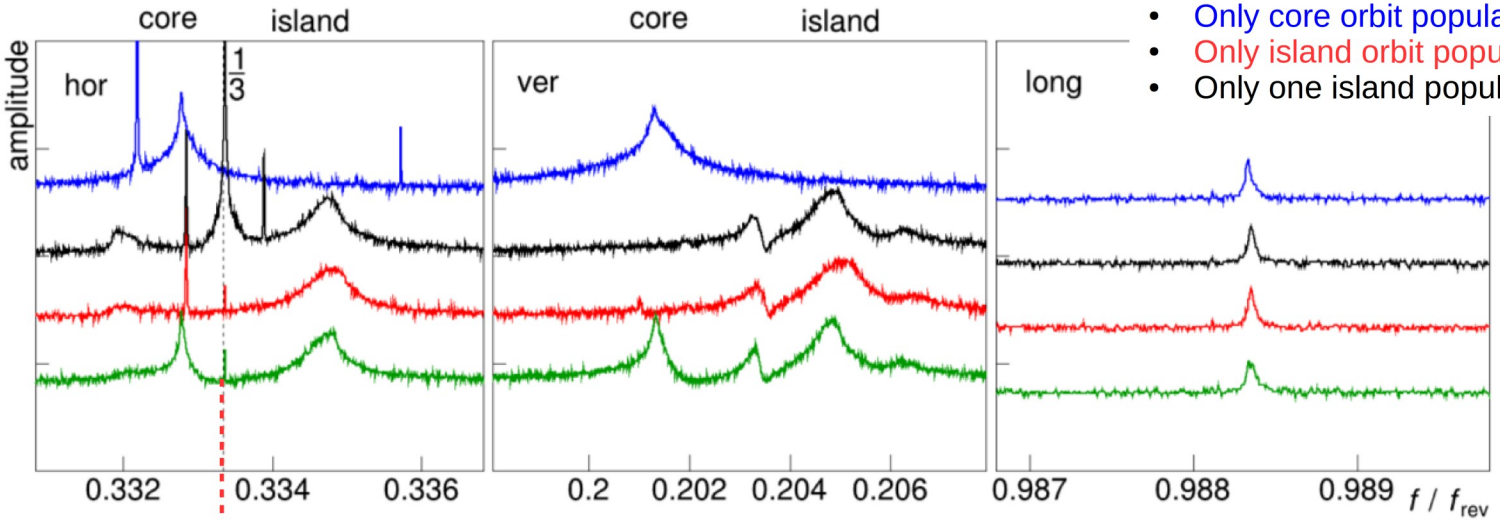
- Move tune towards resonance and manipulate x,x' phase space using chromatic and harmonic sextupoles
- Lifetime, loss rate, tune, source point
- Tune shows deformation near resonance
- Core and island have different tunes separated by resonance

TRIBs at MLS and BESSY II

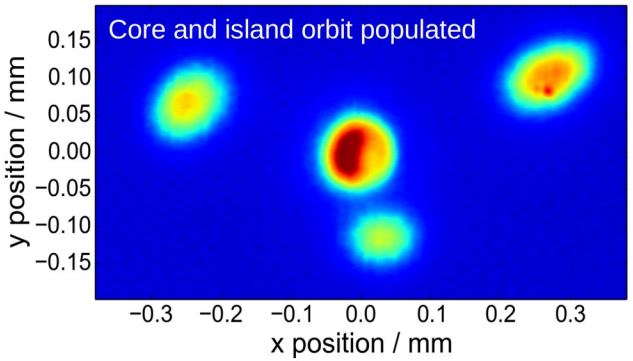
Tunes and current manipulation

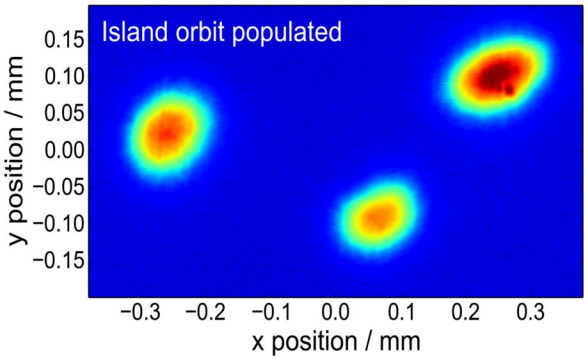
M. Ries et al., Proceedings of IPAC2015, Richmond, VA, USA, MOPWA021

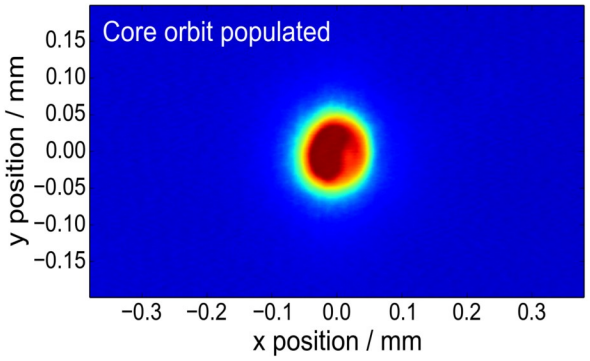
- Core and island orbit populated
- Only core orbit populated
- Only island orbit populated
- Only one island populated



- Current diffusion between core and island orbit, back and forth -> quasi static equilibrium
- Core (or island) tune is resonantly excited to clear core (or island) orbit from current
- With bunch selective excitation -> Placing arbitrary bunches on island orbit, arbitrary fill pattern



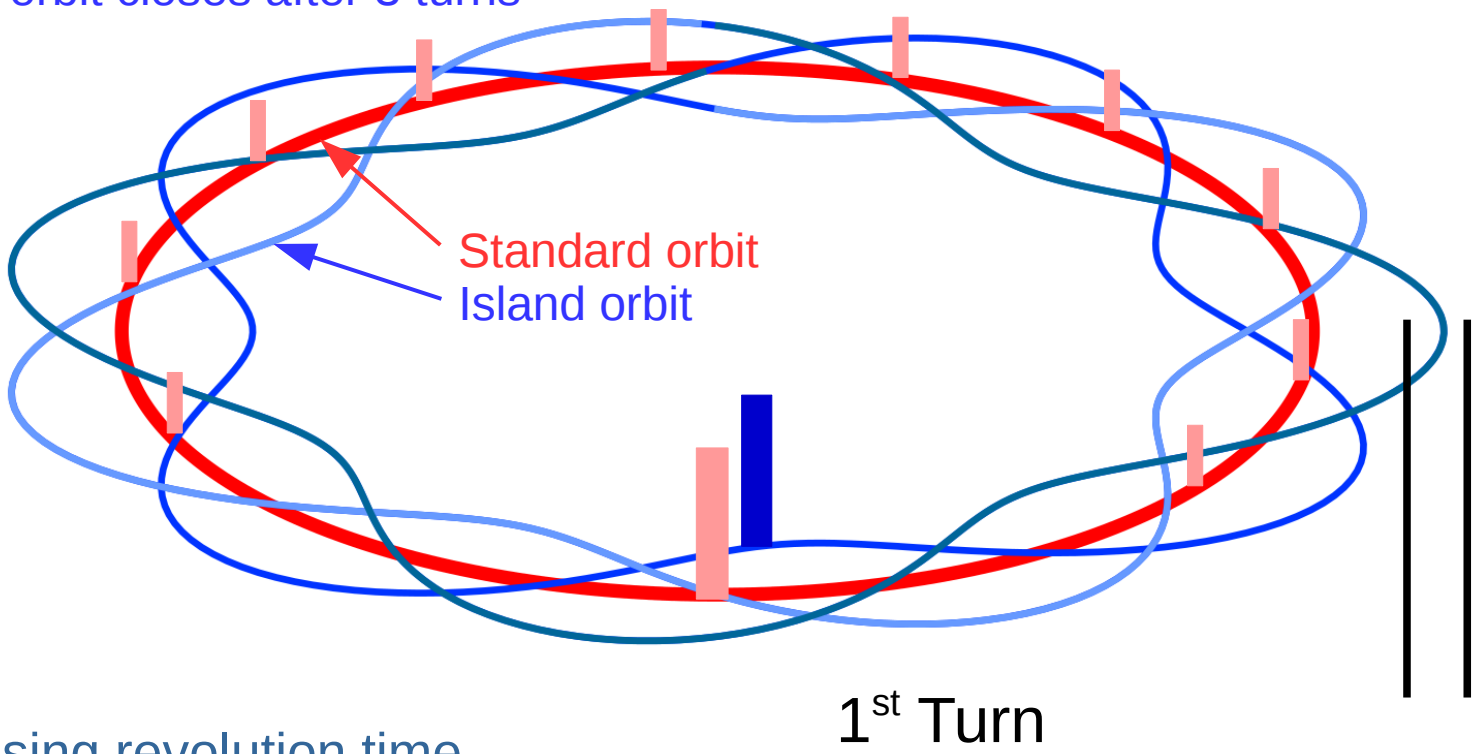




TRIBs - Additional Orbit

Separation scheme using transverse resonance island orbit

3rd order resonance
Island orbit closes after 3 turns



Increasing revolution time

- At small storage rings

TRIBs - Additional Orbit

Separation scheme using transverse resonance island orbit

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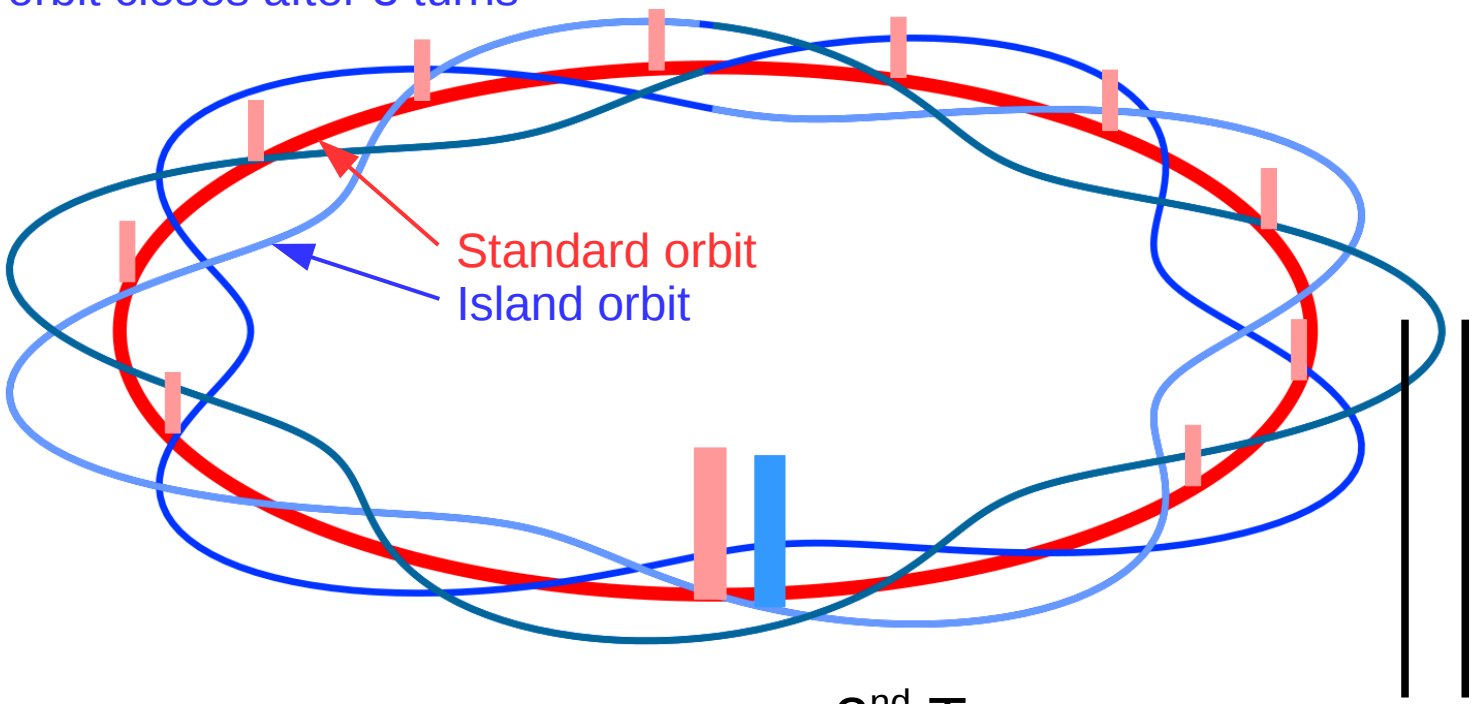


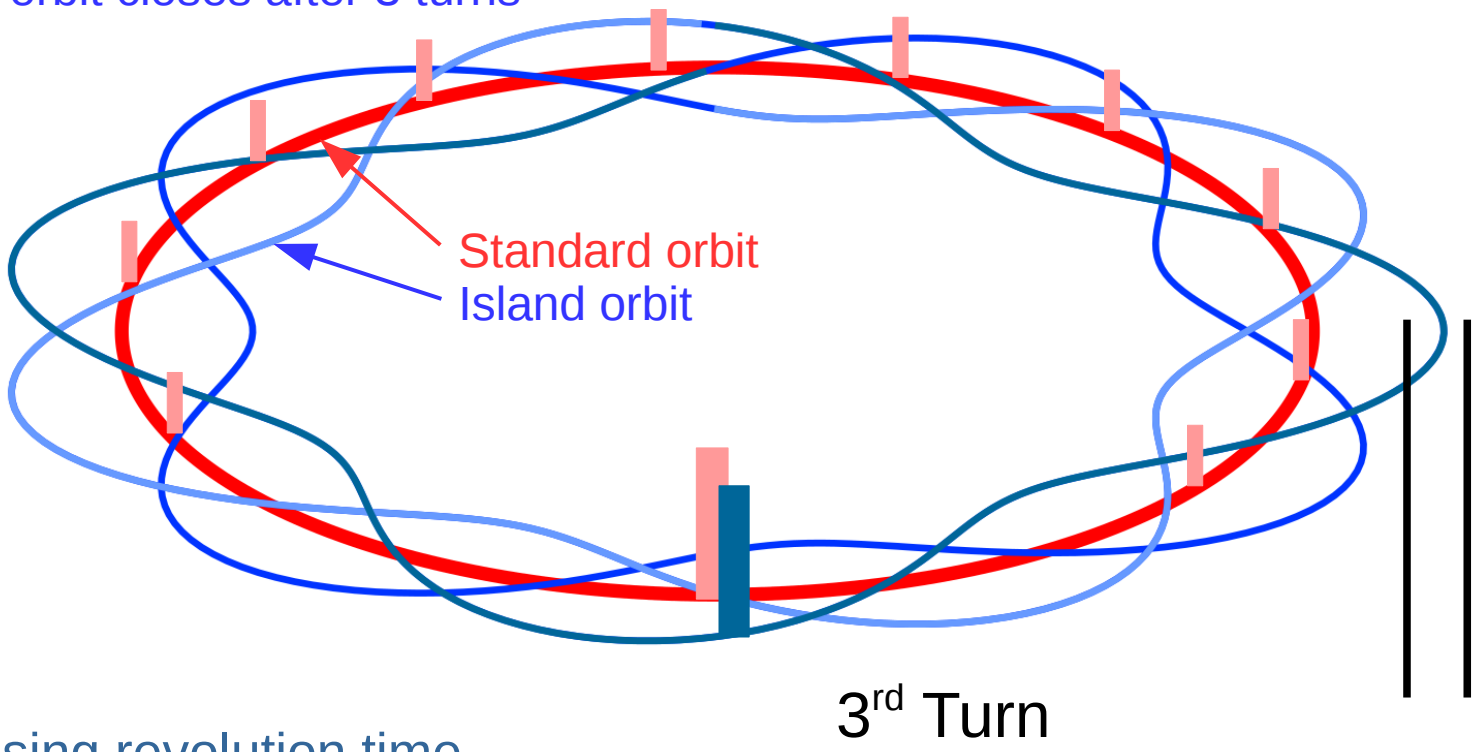
Increasing revolution time

- Decrease repetition rate at small storage rings

TRIBs - Additional Orbit

Separation scheme using transverse resonance island orbit

3rd order resonance
Island orbit closes after 3 turns



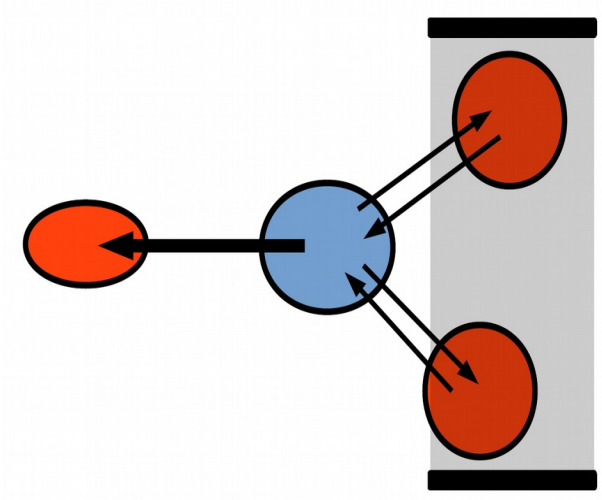
Increasing revolution time

- Decrease repetition rate at small storage rings
- Successful user experiment at the MLS

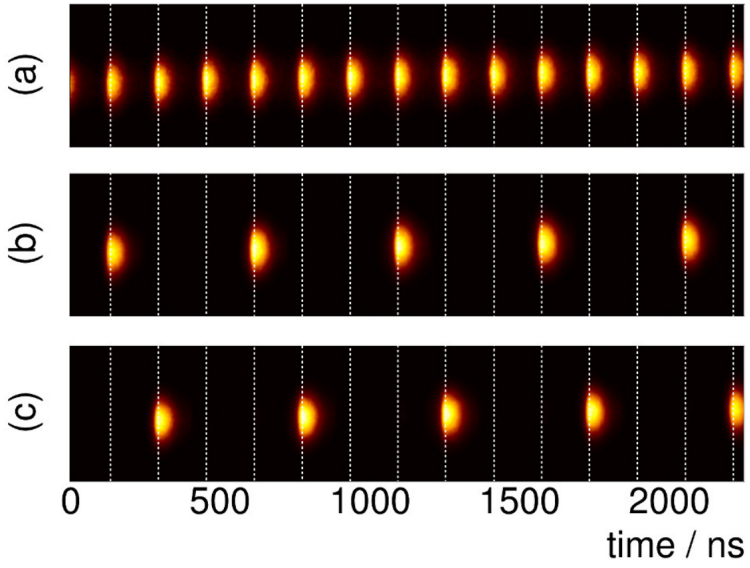
M. Ries et al., Proceedings of IPAC2015, Richmond, VA, USA, MOPWA021

Current manipulation, sub-revolution frequency (MLS)

- 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,
kick-kick-pause
pause every 3rd turn

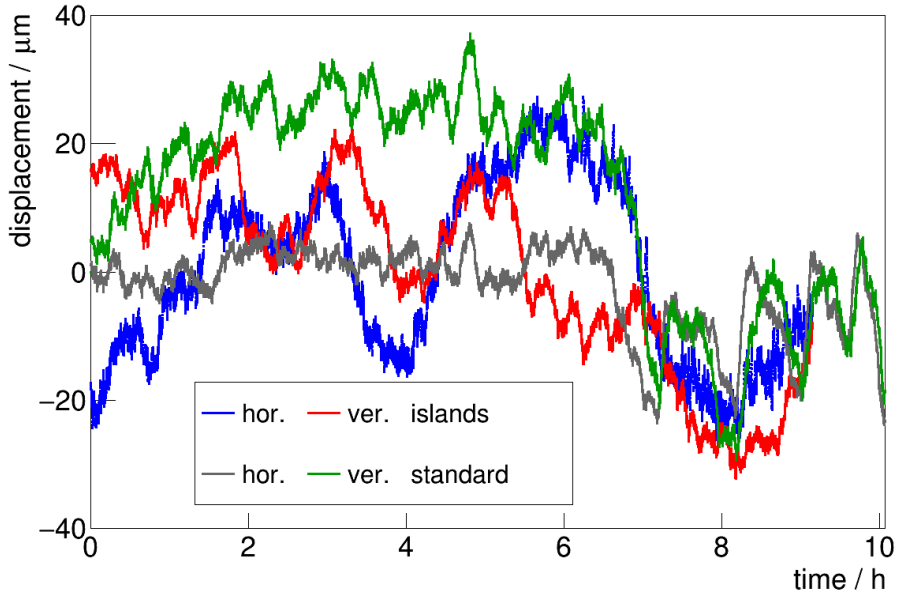
Application:

- Increase revolution time for TOF exp.
  from 160ns to 480ns
- Useable to test bunch resolved diagnostics

TRIBs at MLS - User Experiments

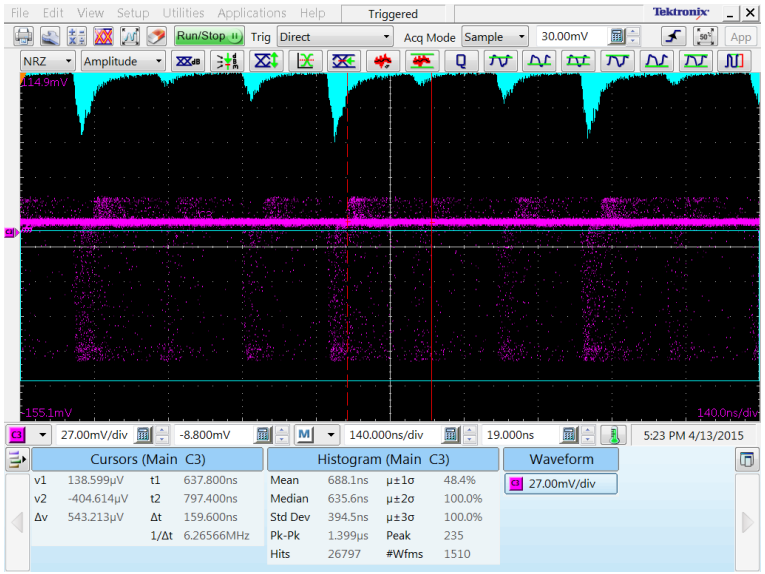
Sub revolution frequency

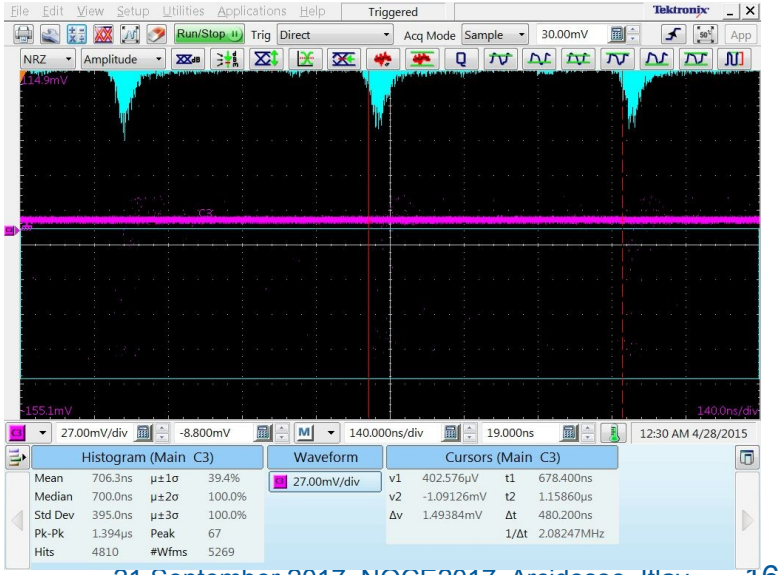
- Reduced revolution frequency of 6.25 MHz to 2.083 MHz by populating only one island (revolution time from 160 ns to 480 ns)
- Two successful user runs of 10 h each in decay mode for ARTOF experiments
- Vertical and horizontal position of source point monitor, without orbit correction, good long term stability of island orbit



M. Ries et al., Proceedings of IPAC2015, Richmond, VA, USA, MOPWA021

Signal measured at ID beamline with channeltron





TRIBs at BESSY II - Towards realistic user operation

Proof of principle experiments

Since 2015

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

Fall 2015

- **Separation - good enough?**
  Electron separation -> Photon pulse separation?
  - Align island orbit on dipole/ID beamline
  - Purity, Diffusion rates, SNR
  - Usable at all beamlines at the same time ?
  - Impact of radiation from island orbit on standard orbit?

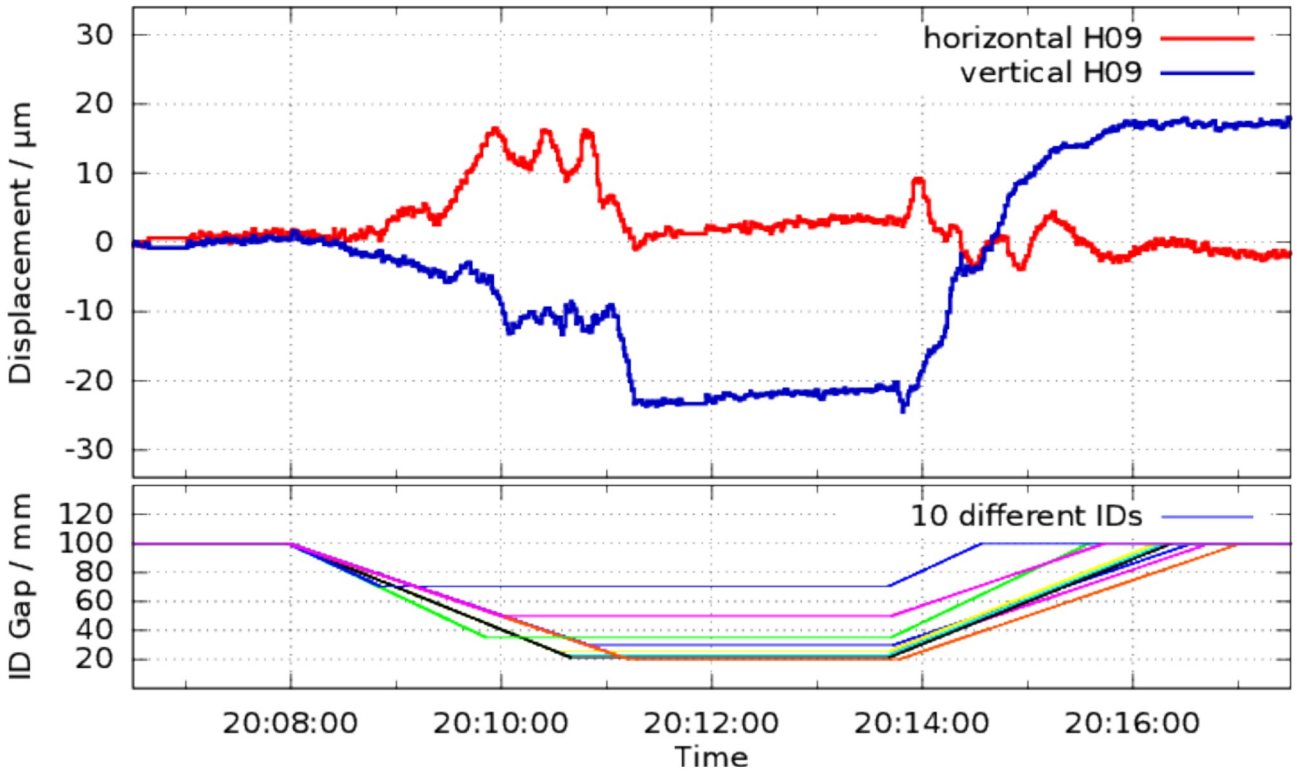
Fall 2016

- **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?

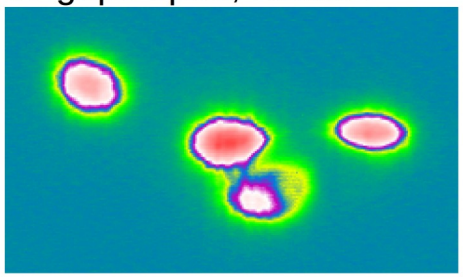
User test week
in February 2018

High current operation and moving ID gaps

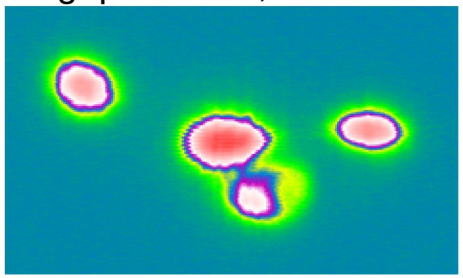
- High current operation possible: 300 mA (all in core or island)
- Closing gaps of 10 undulators shows a position change of ±20 µm
  - Without orbit correction and tune feedback, but with feedforward for standard optic



ID gaps open, 200mA



ID gaps closed, 200mA



TRIBs at BESSY II - Separation (Oct2015)

First experiments with in-house users at BESSY II

Island buckets as separation scheme?

- One bending magnet beamline (**PM4**)
- Four ID beamlines (**UE56-1, UE112**, UE49, UE46)

Many thanks to
K. Holldack, R. Ovsyannikov, G. Schiwietz
F. Kronast, E. Schierle,
M. Mast, C. Jung, F. Schäfer

- **When all current is pushed in island orbit, photon flux of the core beam vanishes completely at most beamlines**
  - Beamline acceptance of most undulator beamlines ≈ 0.2 mrad
  - Orbit separation is much larger of about ≈ 0.3 mrad
  - Synchrotron radiation opening angle:

$$\theta = \frac{1}{\gamma} = \frac{1}{3327} = 0.3\,\mathrm{mrad}$$

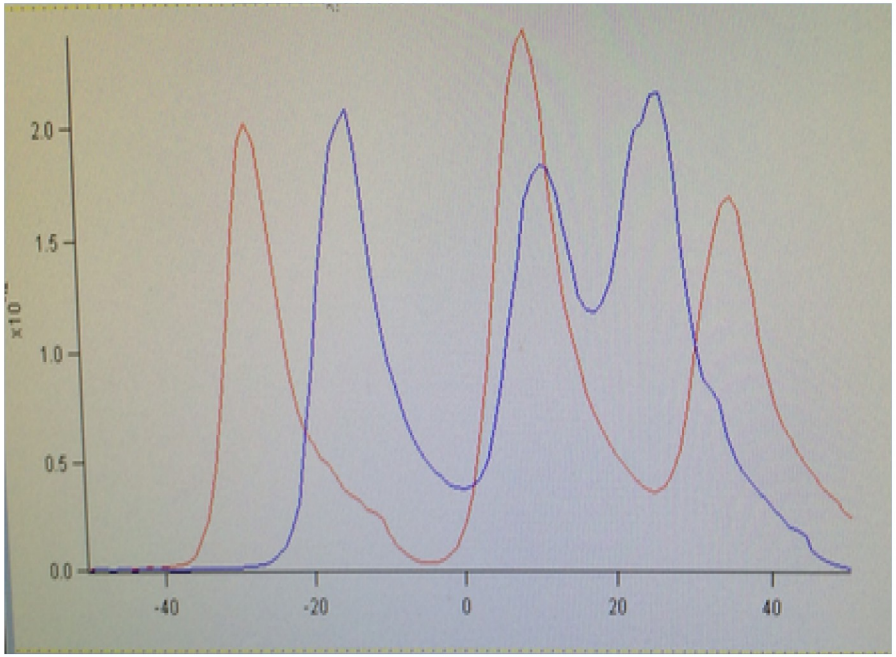
TRIBs at BESSY II - Separation bending magnet

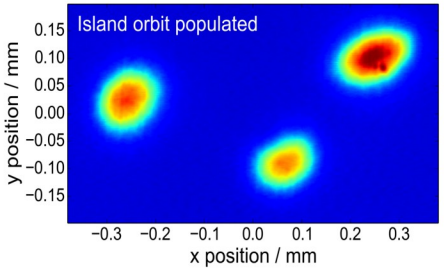
Bending magnet beamline PM4

- Intermediate focus and moveable slit (because of MHz chopper)
- Source point mapped by a horizontal scan of first mirror
- Displacement of outer island spots of 0.5 mm at a source size of 0.1 mm -> 4σ separation
- Once only single bunch in island end-stations sees a clean 1.25 MHz signal
- ARTOF on gold with SB in island orbit in parallel to MB fill on standard orbit

First scan

Second scan after improving beam separation

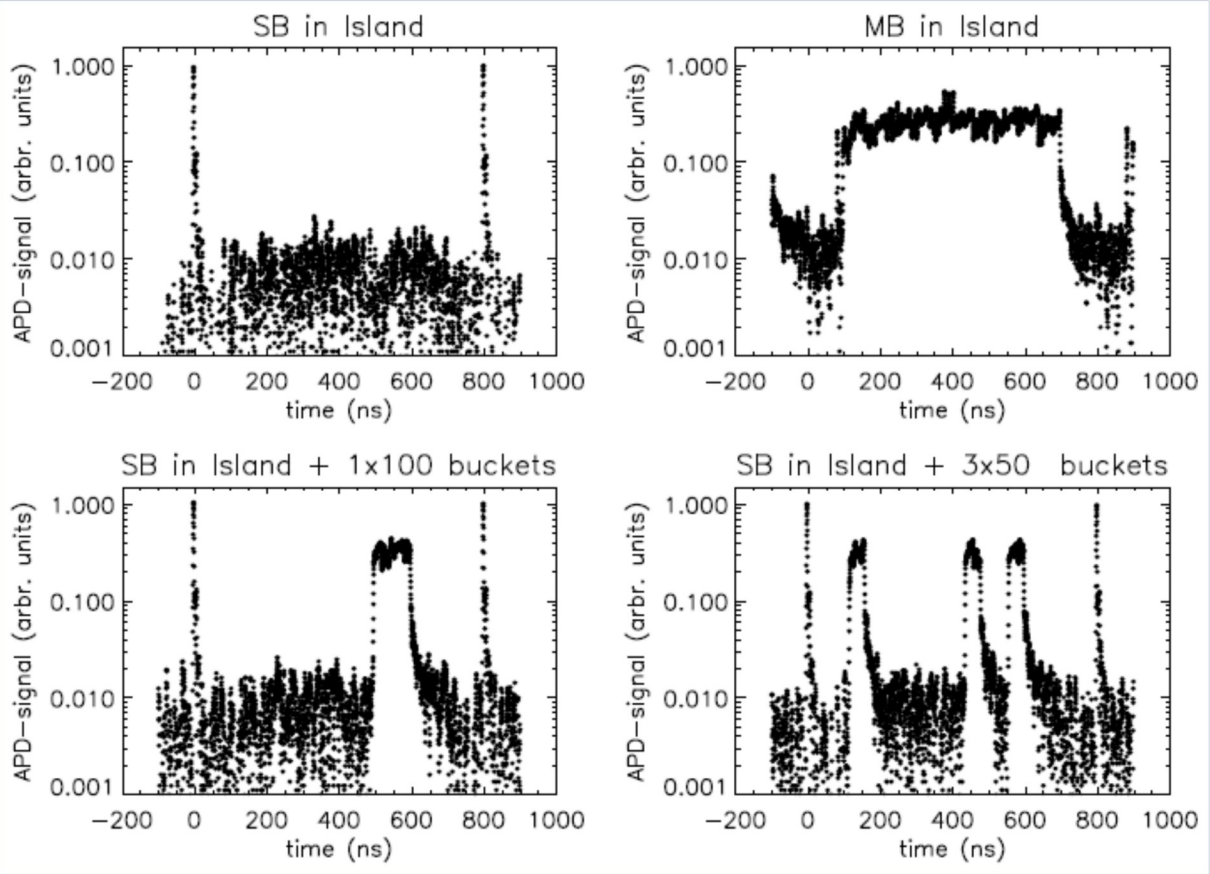




ID UE56-1 ZPM vertical polarized

- Signal measured with avalanche photodiode, fast enough to resolve fill pattern
- Photons of 3rd undulator harmonic, 831eV linear vertical polarised

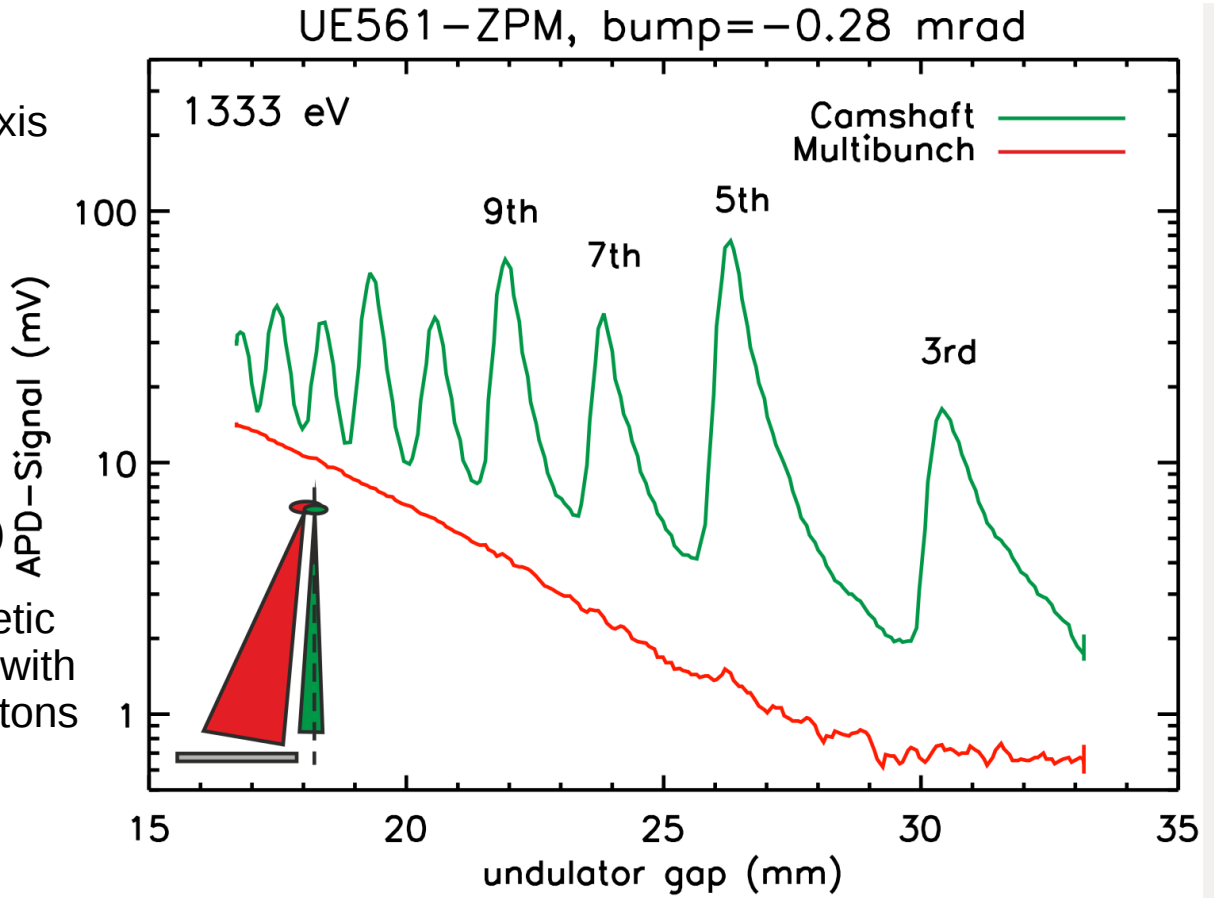
- Align island orbit on ID axis
  - Orbit bump of 0.23 mrad
  - Pinhole displacement of 0.8 mm
- Signal ratio SB/MB: Purity -> 100
- Arbitrary fill pattern within seconds



ID UE56-1 ZPM elliptical polarised

- UE56 operated in elliptical mode (shift 25), elliptical polarised 1333eV
- Only Camshaft in island orbit, photons of 5th undulator harmonic

- Orbit bump with 0.28 mrad to align island orbit on ID axis
- Camshaft from island orbit shows undulator spectrum while MB fill from standard orbit is far off axis and blocked by aperture
- Purity -> 100 (5th harmonic)
- Time resolved X-ray magnetic circular dichroism (XMCD) with camshaft island bunch photons

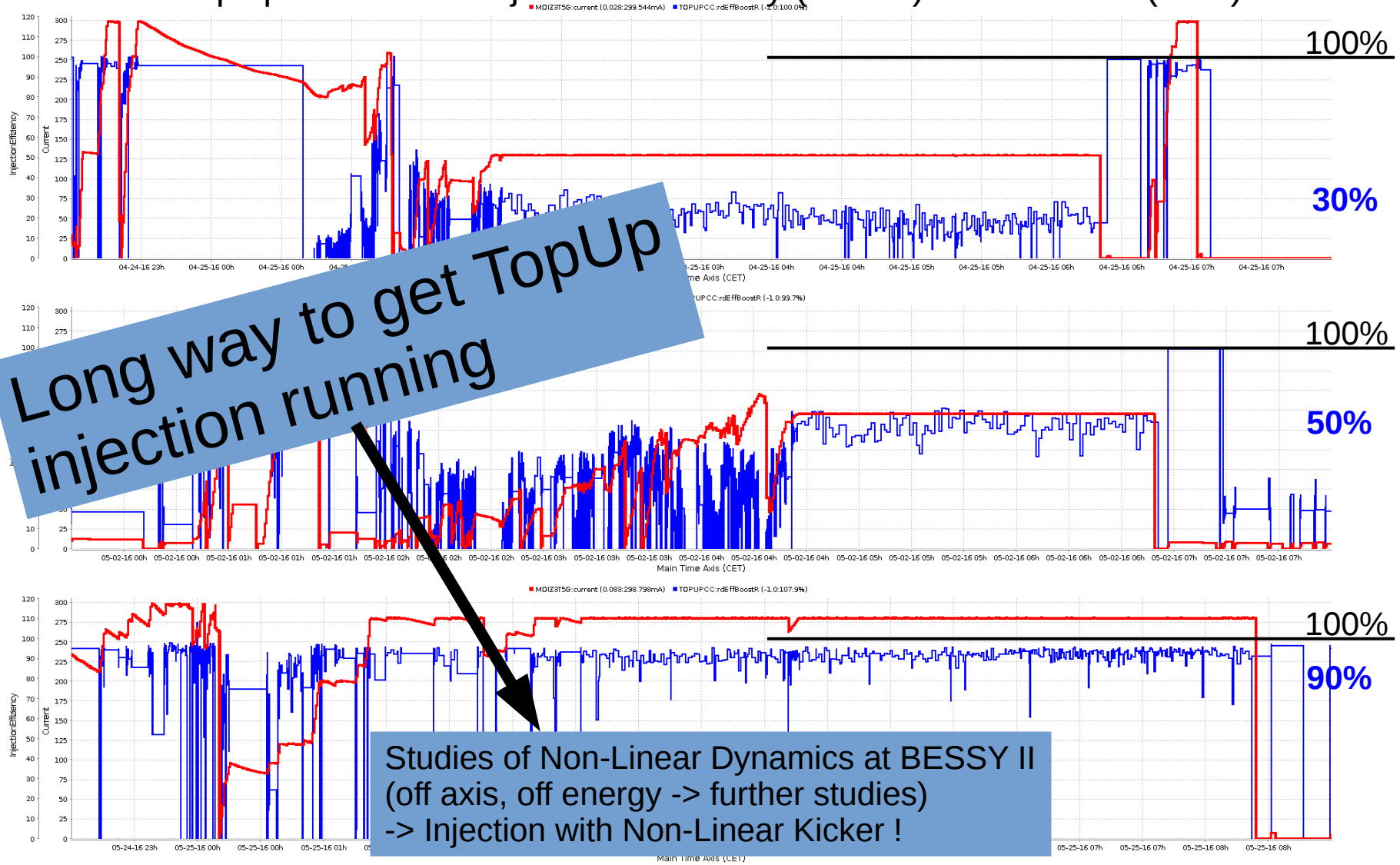


TRIBs at BESSY II - TopUp Injection

Further developments of island buckets at BESSY II

– Current
– Injection Efficieny

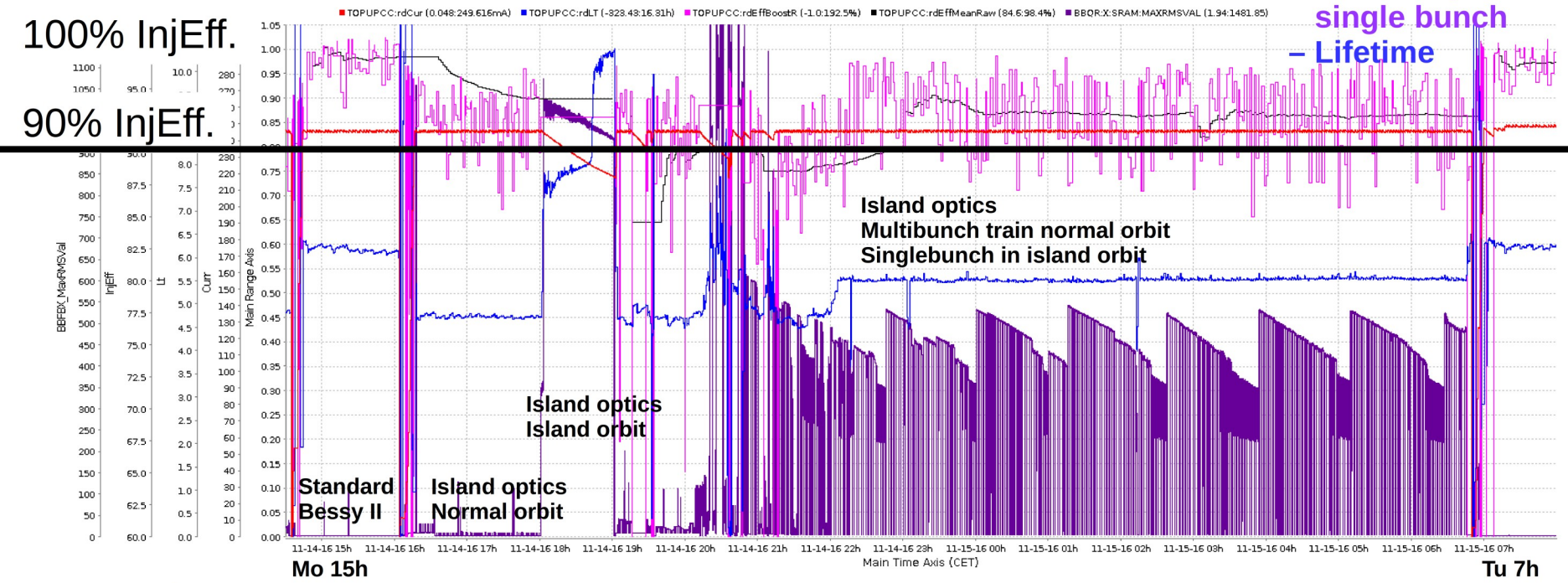
- Fulfil TopUp conditions: Injection Efficiency (> 90%) and Lifetime (> 5h)



TRIBs at BESSY II - TopUp Injection (Nov2016)

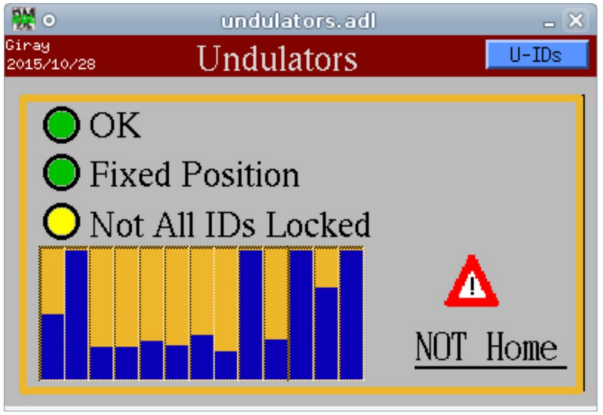
November 2016 – Proof of principle Experiments
TRIBs in TopUp with open beamshutters and most IDs closed!

– Current
– Injection Efficieny
– Island Signal single bunch
– Lifetime



Result:

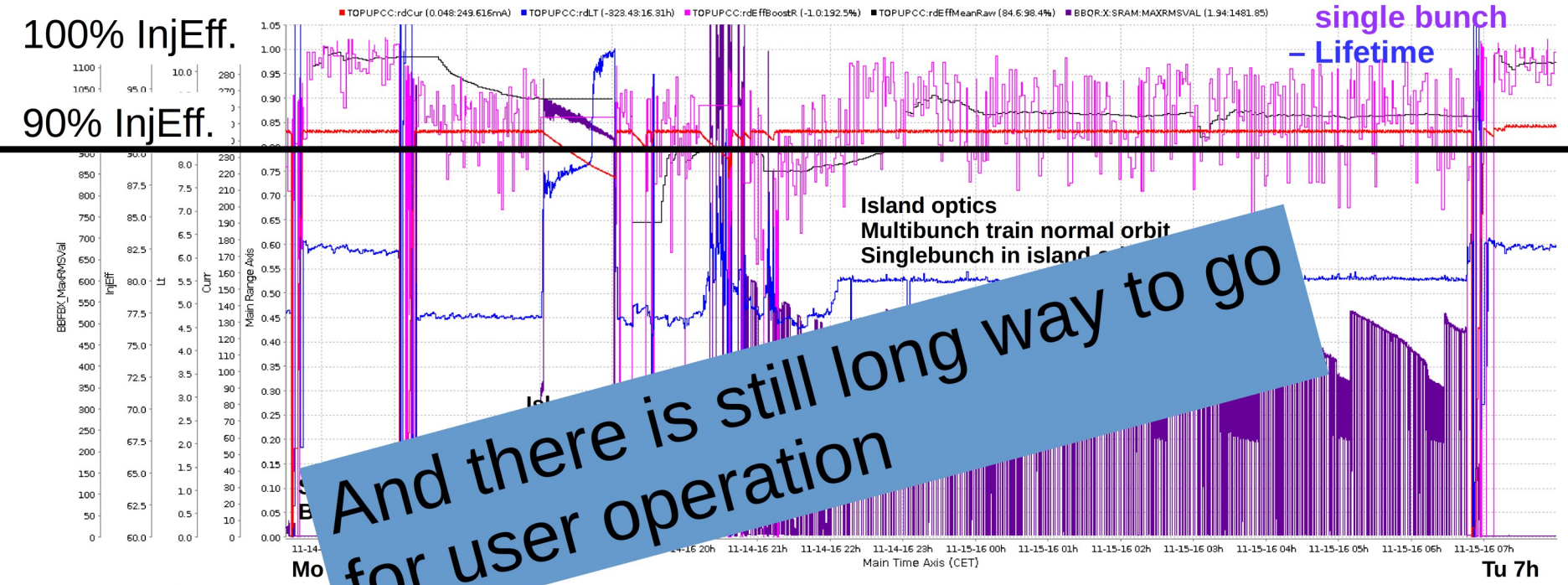
- Island optics with single bunch on island orbit over night (8h) in TopUp with open beamshutters and 9 IDs and some dipoles beamlines participating
- Stable operation, but improvable !
  -> balance between separation and injection !
- Many techniques not prepared for island operation, for example: ID correction



TRIBs at BESSY II with TopUp

November 2016 – Proof of principle Experiments
TRIBs in TopUp with open beamshutters and most IDs closed!

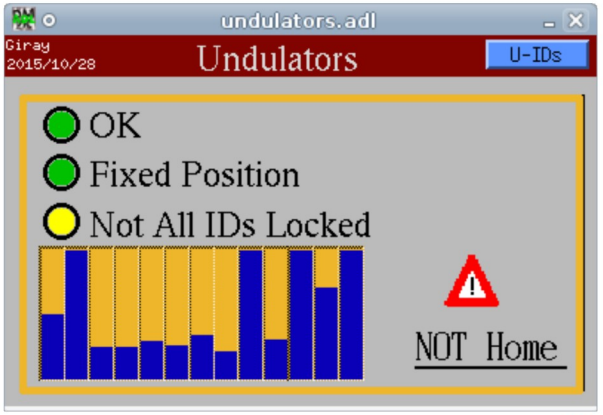
– Current
– Injection Efficieny
– Island Signal single bunch
– Lifetime



And there is still long way to go for user operation

Result:

- Island optics with single bunch on island orbit over night (8h) in TopUp with open beamshutters and 9 IDs and some dipoles beamlines participating
- Stable operation, but improvable !
  -> balance between separation and injection !
- Many techniques not prepared for island operation, for example: ID correction

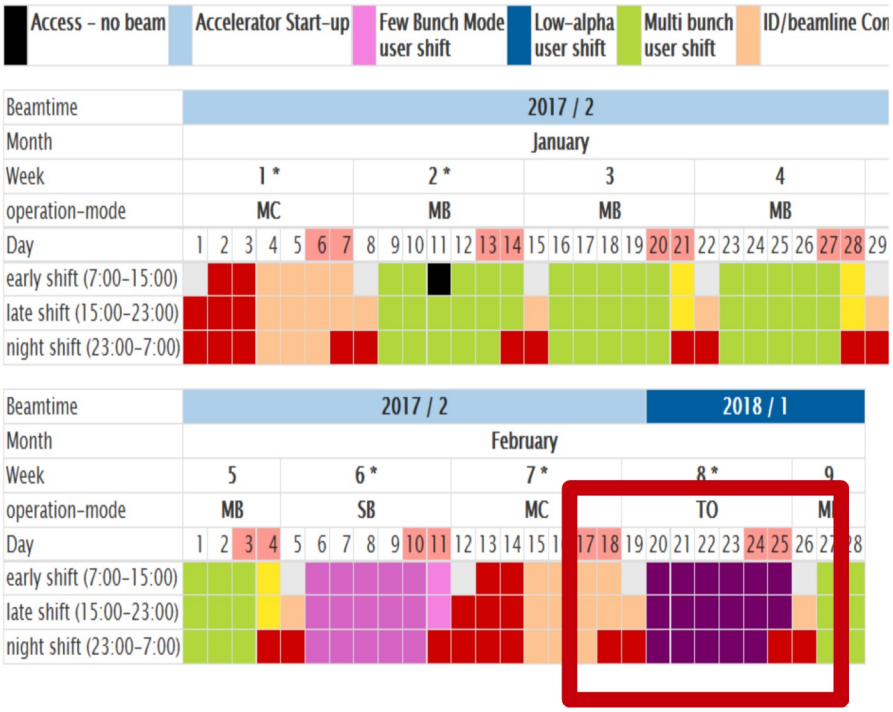


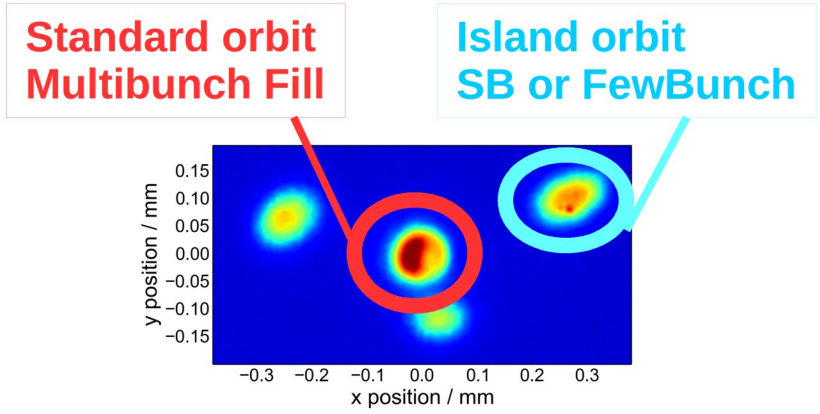
TRIBs at BESSY II – User Test Week

Further steps

- Deeper understanding of island orbit -> characterisation
- More common experiment during machine startup and beamline commissioning
  - TopUp Injection and Separation

- **TWIN Orbit User Test (user shift) 19-25 February 2018**
  purple in beamtime schedule





More information or want to participate:

> User office: A. Vollmer, F. Staier

> paul.goslawski@helmholtz-berlin.de

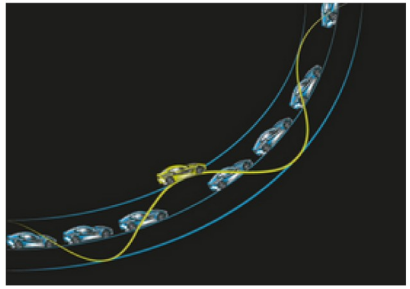
Summary: TRIBs at BESSY II / MLS

Summary

- **Separation scheme**, two stable orbits in one machine, 2nd lane, 2nd fillpattern
  - Established user operation at decaying machine with one ID (MLS), -> increasing revolution time
  - Studies towards user operation in a 3rd generation lightsource, -> combine with TOPUP injection scheme, many IDs (BESSY II / VSR)
  - TRIBs Videos: Separation: https://www.youtube.com/watch?v=FRq9pT_sETQ Injection: https://www.youtube.com/watch?v=SA9wccisUJ8

- **User Test Week at BESSY II in February 2018**

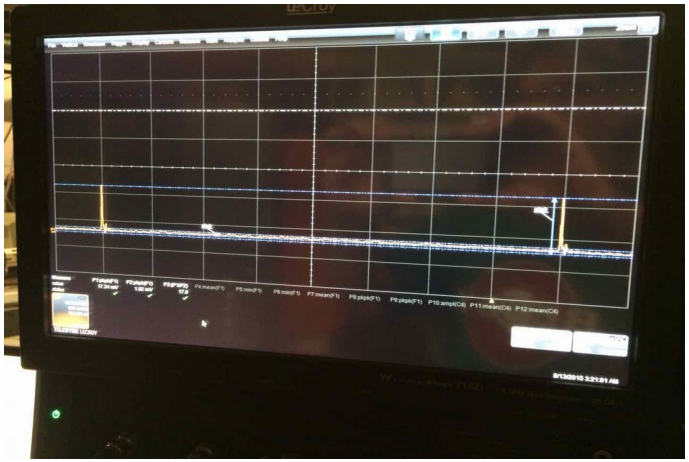
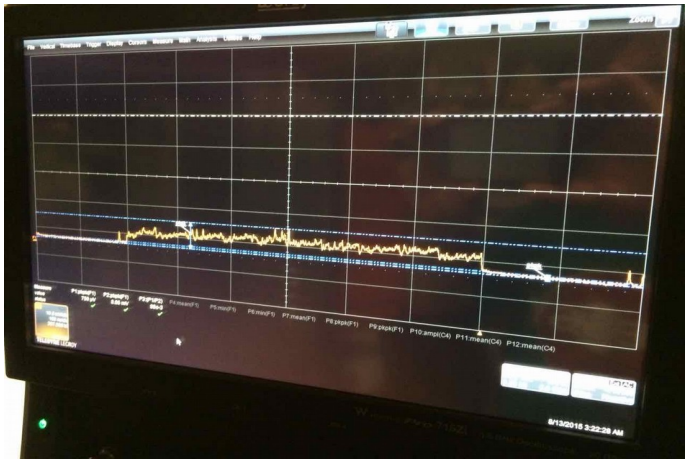
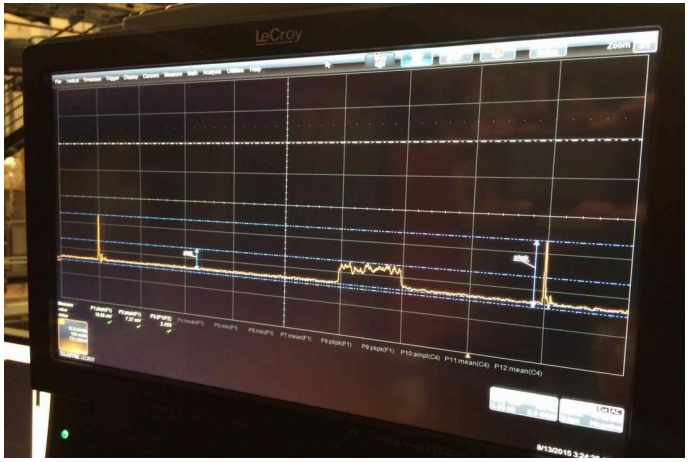
BESSY II electron highway gets second lane

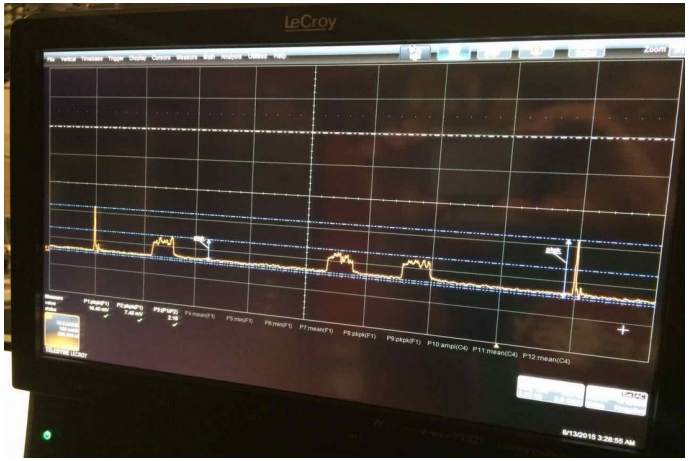


The picture illustrates a hypothetical highway with the second path winding around the first one. Experimenters at the beamlines could then either use the dense sequence of light pulses from the primary electron path or select individual light pulses from the secondary orbital track. Image: Heike Cords/HZB

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.

Thank you for your attention



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