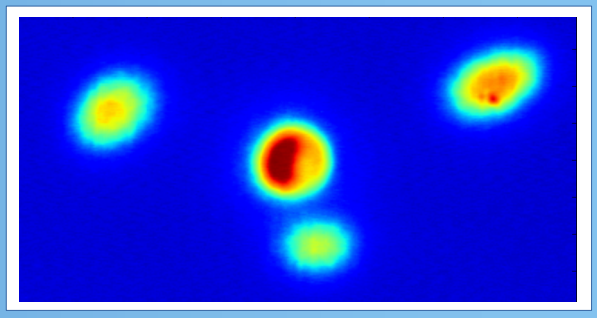
# Two Orbit Operation at BESSY II during a User Test Week

## Transverse Resonance Island Buckets at BESSY II and its User Application

P. Goslawski
Institute for Accelerator Physics
Helmholtz-Zentrum Berlin



19th - 24th May 2019
10th IPAC2019, Melbourne, Australia

# Overview

- **T**ransverse **R**esonance **I**sland **B**uckets

  **TRIBs** at HZB, i.e., at BESSY II (and MLS)

  - Definition, Studies, Experiments, Application, Outlook

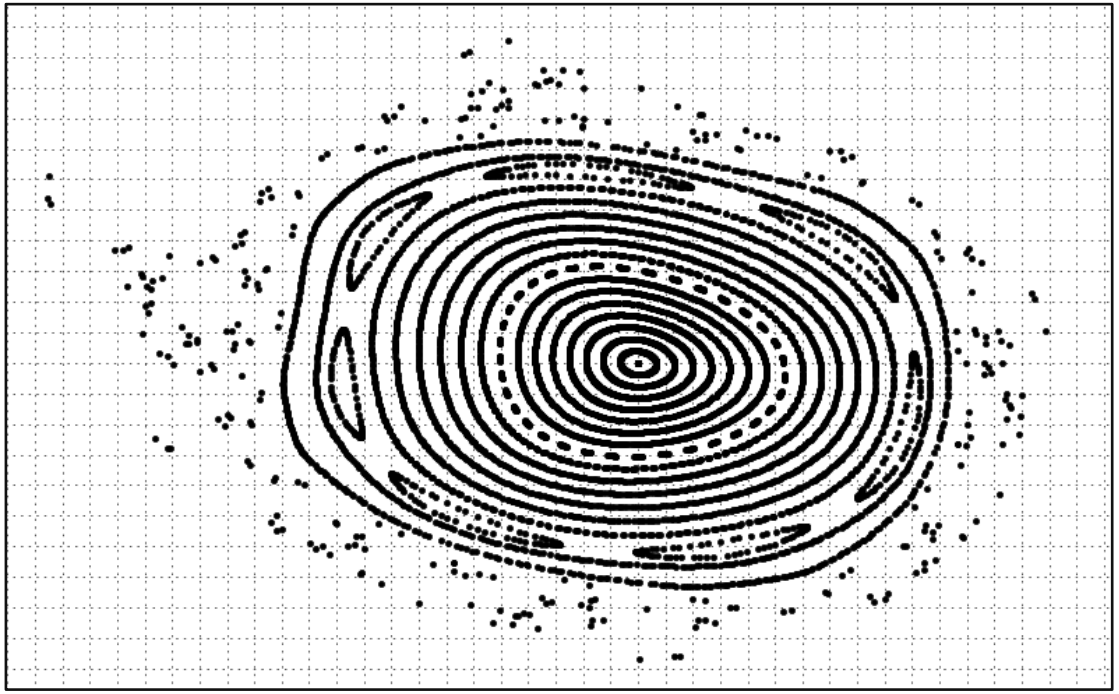
- Motivation

  - Why TRIBs at BESSY II / VSR (and MLS - Metrology Light Source) ?
  - TRIBs for DLSR ?

**BESSY II:**
1.7 GeV, 240 m, DBA, 5 nm rad
Soft X-ray, **Spectroscopy, Timing**

**MLS, Metrology Light Source:**
630 MeV, 48 m, DBA, 100 nm rad
VUV, EUV, THz, low (negative) α

# TRIBs - Additional Stable Fixed Points



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

## Application: multiturn extraction

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

## No Application at Light Sources 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

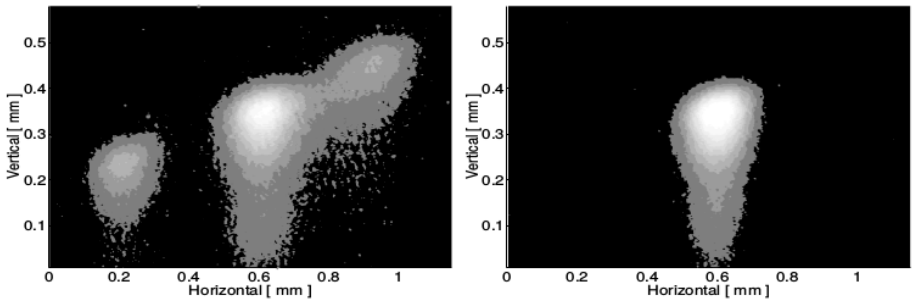
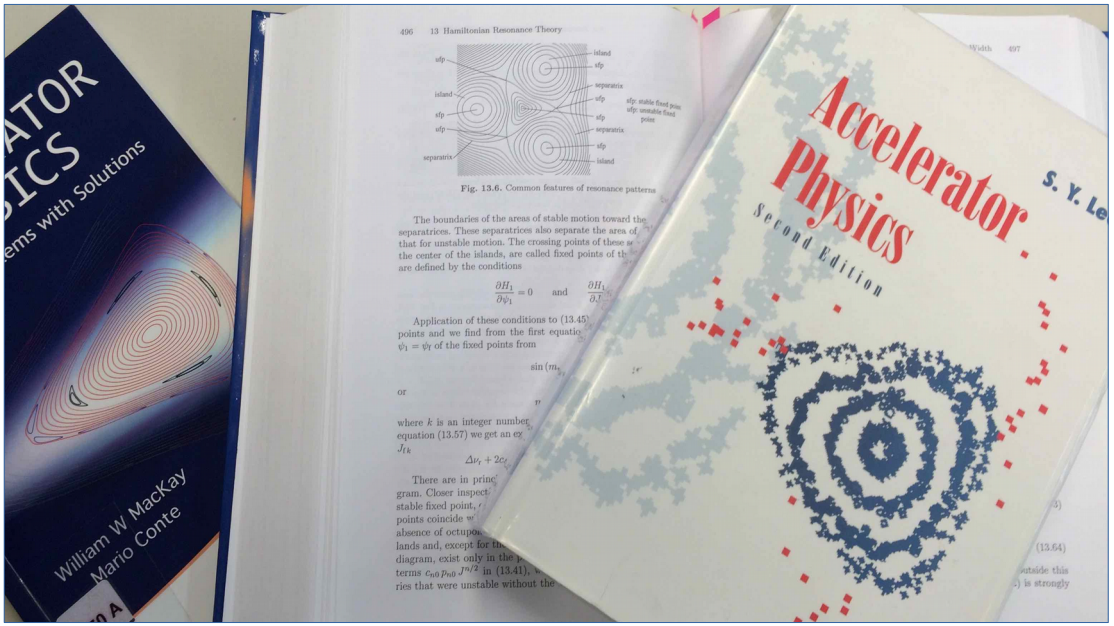



FIG. 14. Synchrotron radiation image of the beam near the $3\nu_x$ resonance. Left is the situation before the optic is corrected and right is the situation after the optic is corrected. (The plane of the camera is rotated with respect to the plane of the beam.) Also there is a distortion in the light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

# TRIBs - Not new

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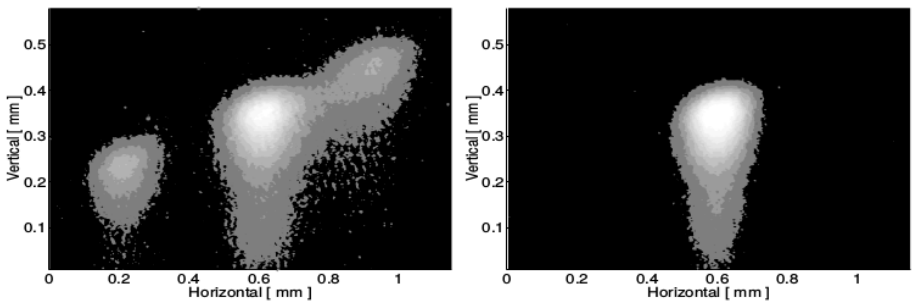


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# TRIBs - Not new

Tree felled by family Kuske

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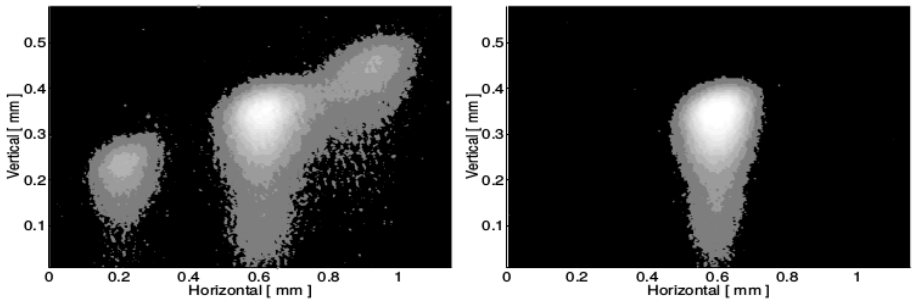


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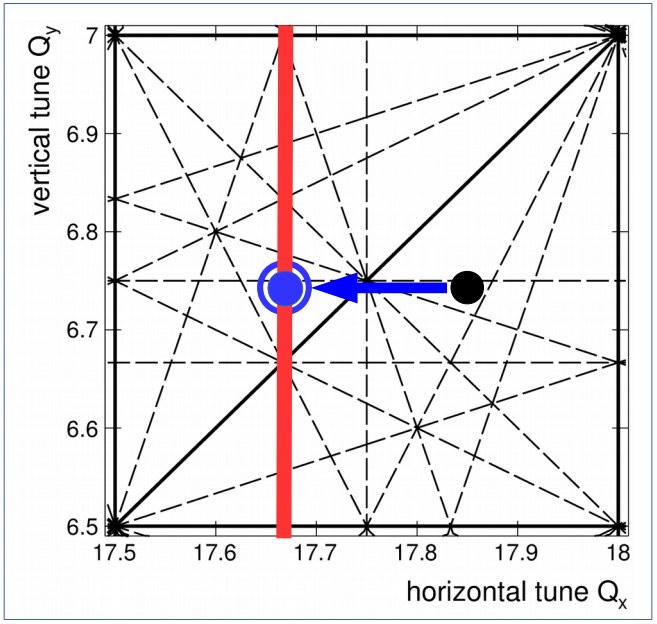
# TRIBs – Working point “on” resonance

## 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

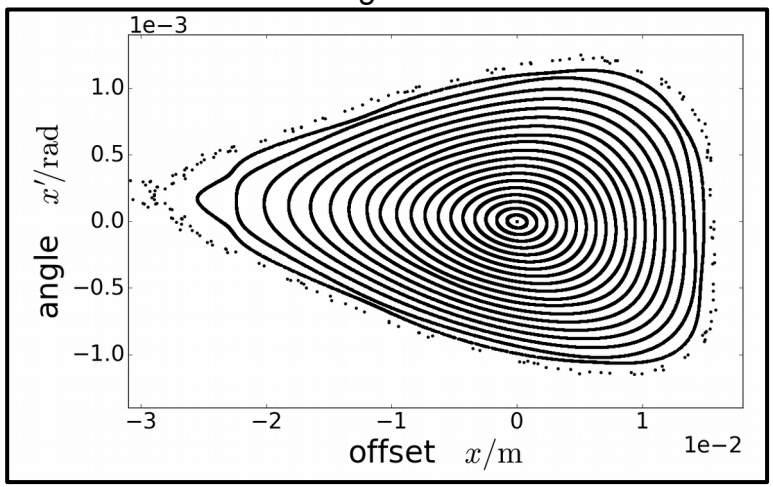



● BESSY II working point (17.85, 6.73)

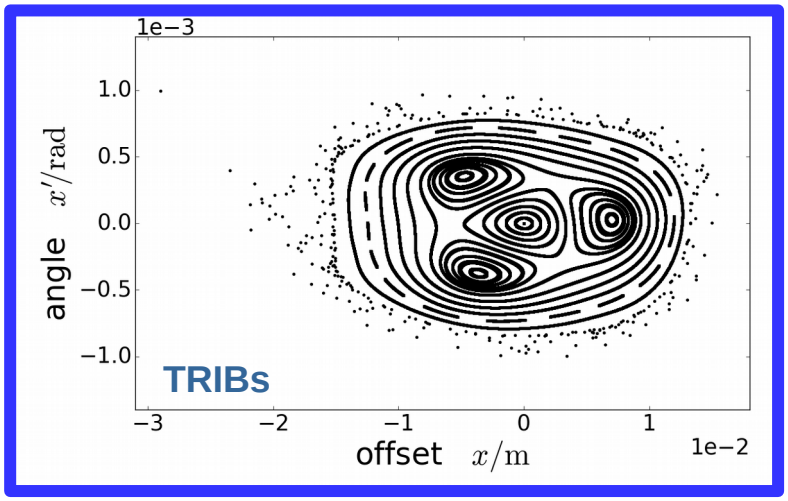
● BESSY II TRIBs at 3rd order (17.66, 6.73)

## 2nd stable fix point & orbit

● BESSY II standard setting

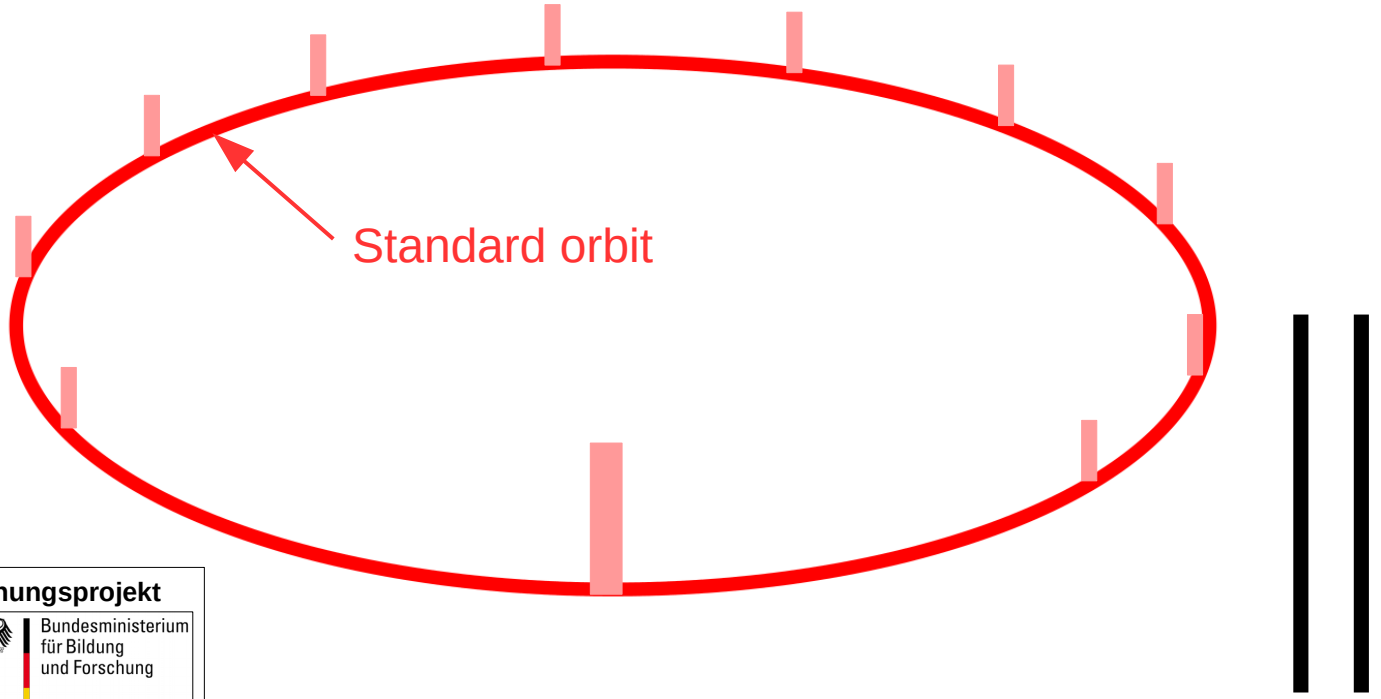



● BESSY II TRIBs at 3rd order resonance



# 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 2x
- TopUp Injection into TRIBs
- Timing Modes for Adv. Lightsources

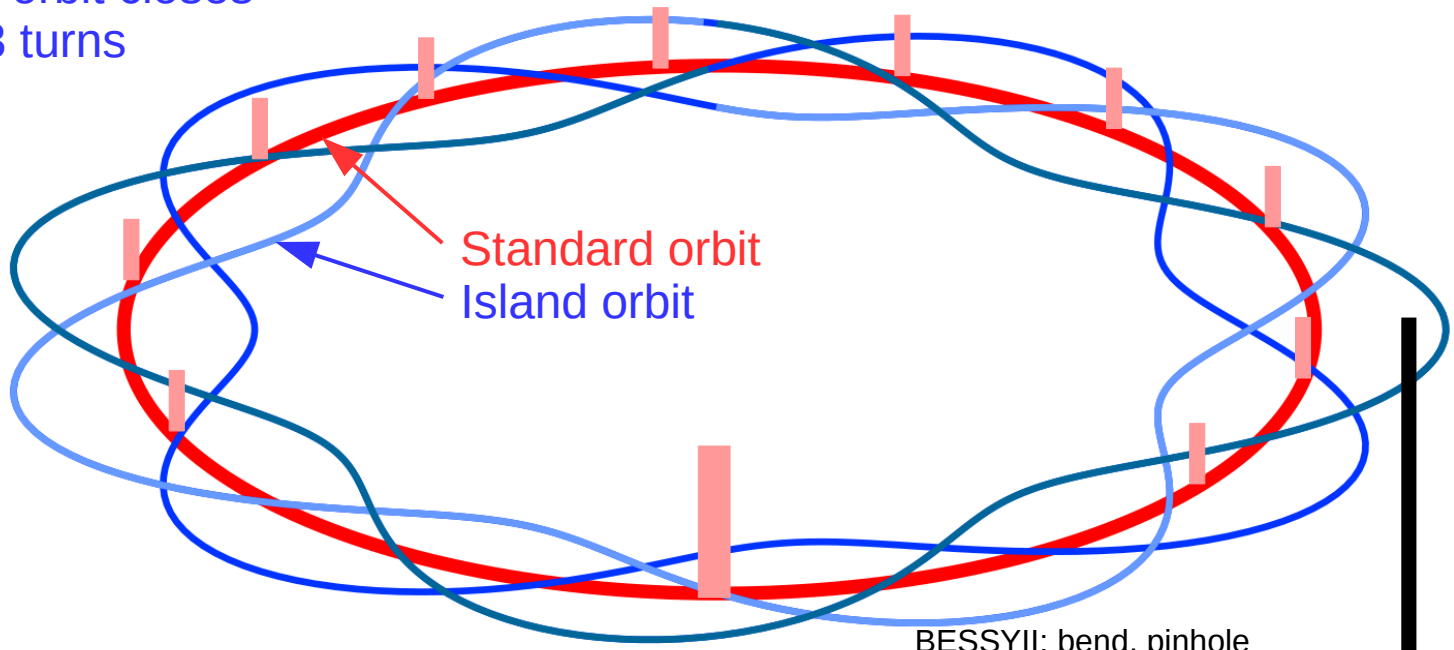
Stable 2nd closed orbit for bunch separation

Aim: Multiple beam storage with island buckets

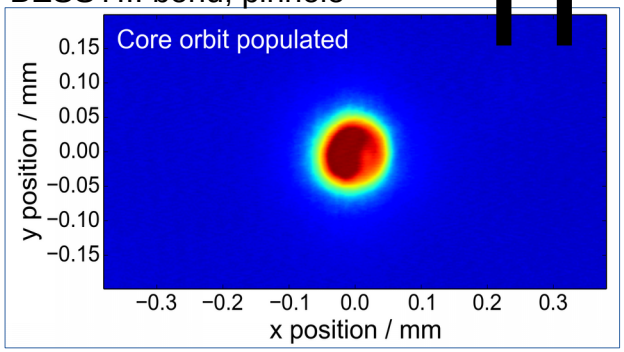
# Application: A new electron bunch separation scheme

## 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**

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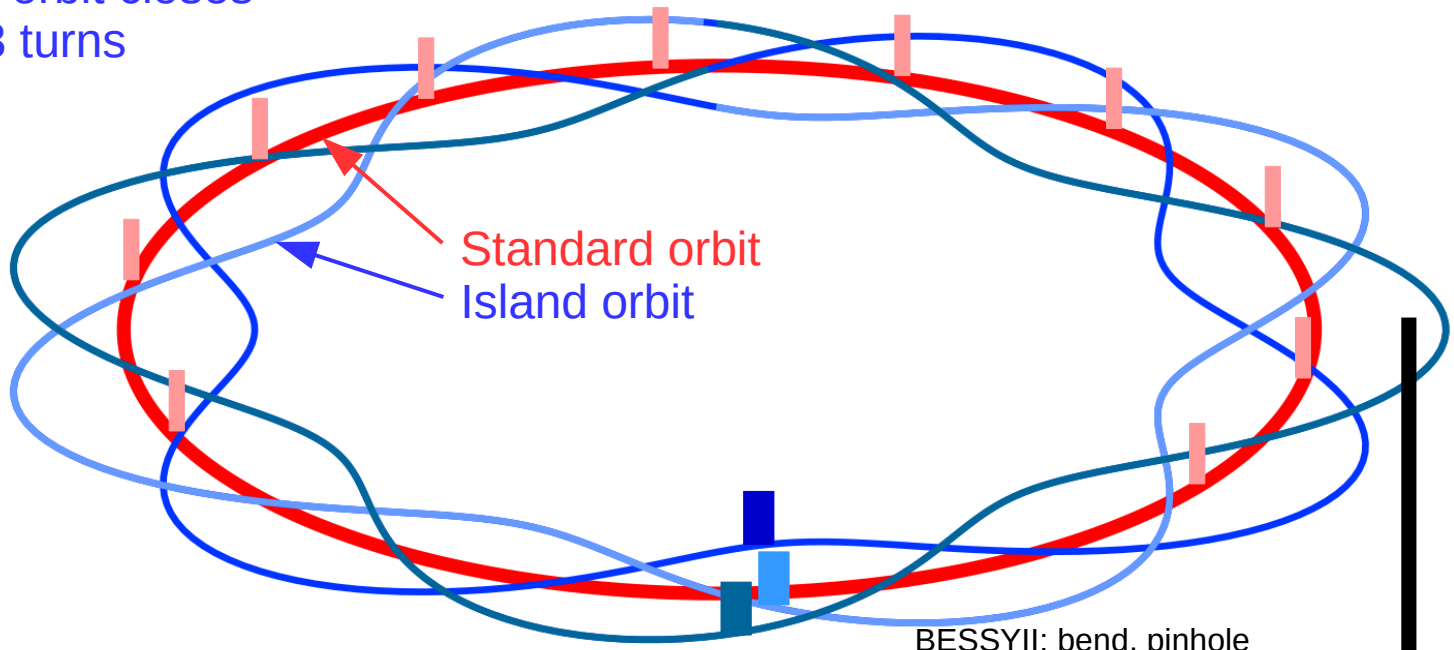


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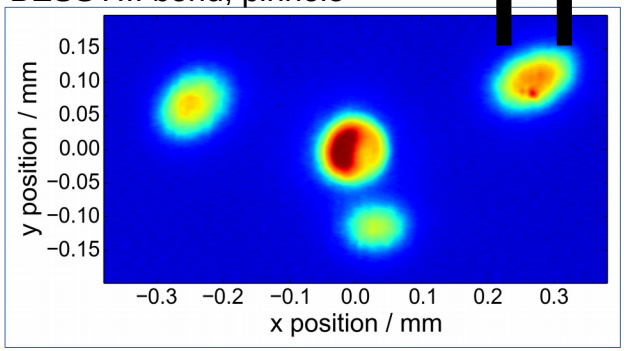


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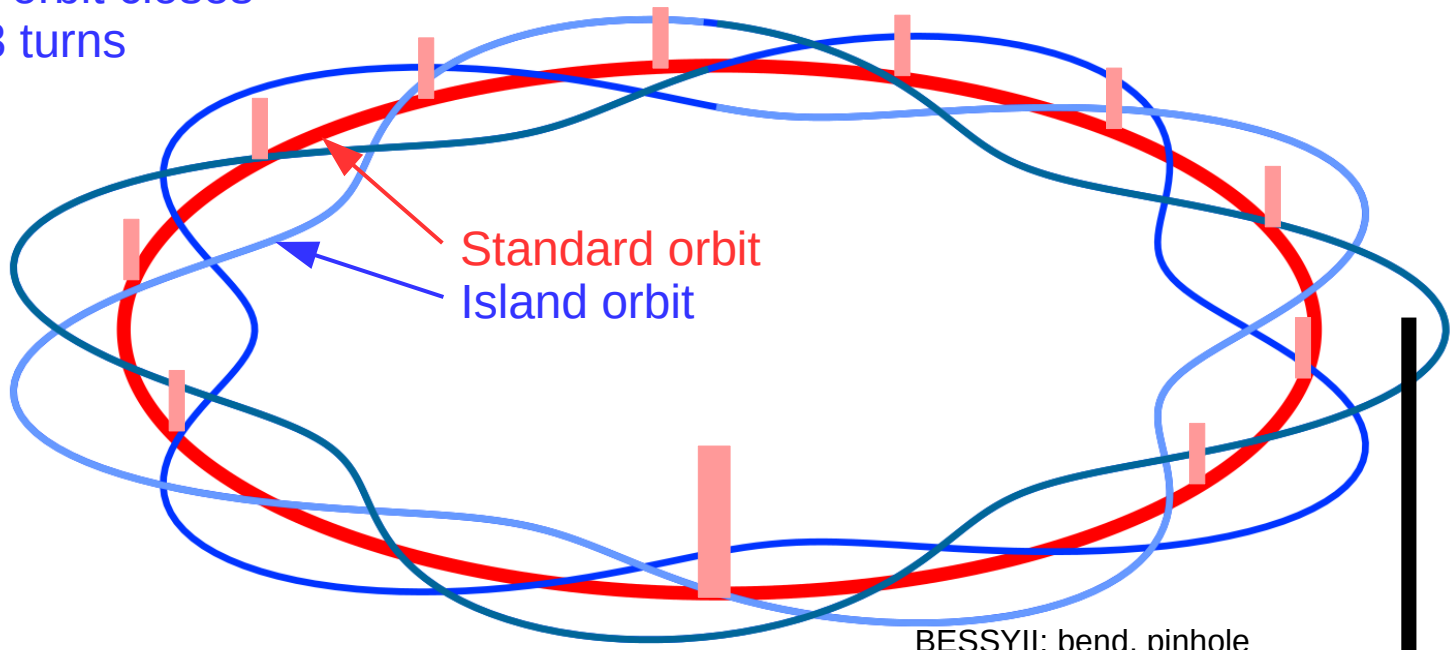


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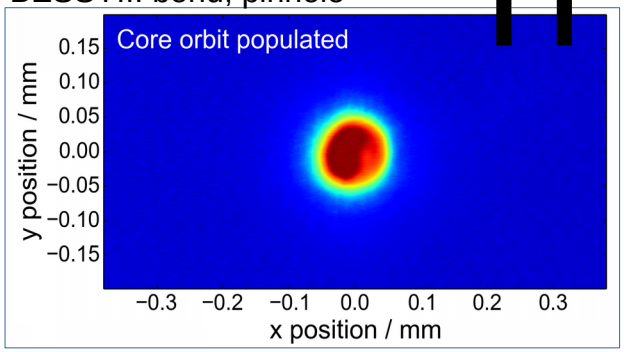


Two stable independent orbits
capable to store
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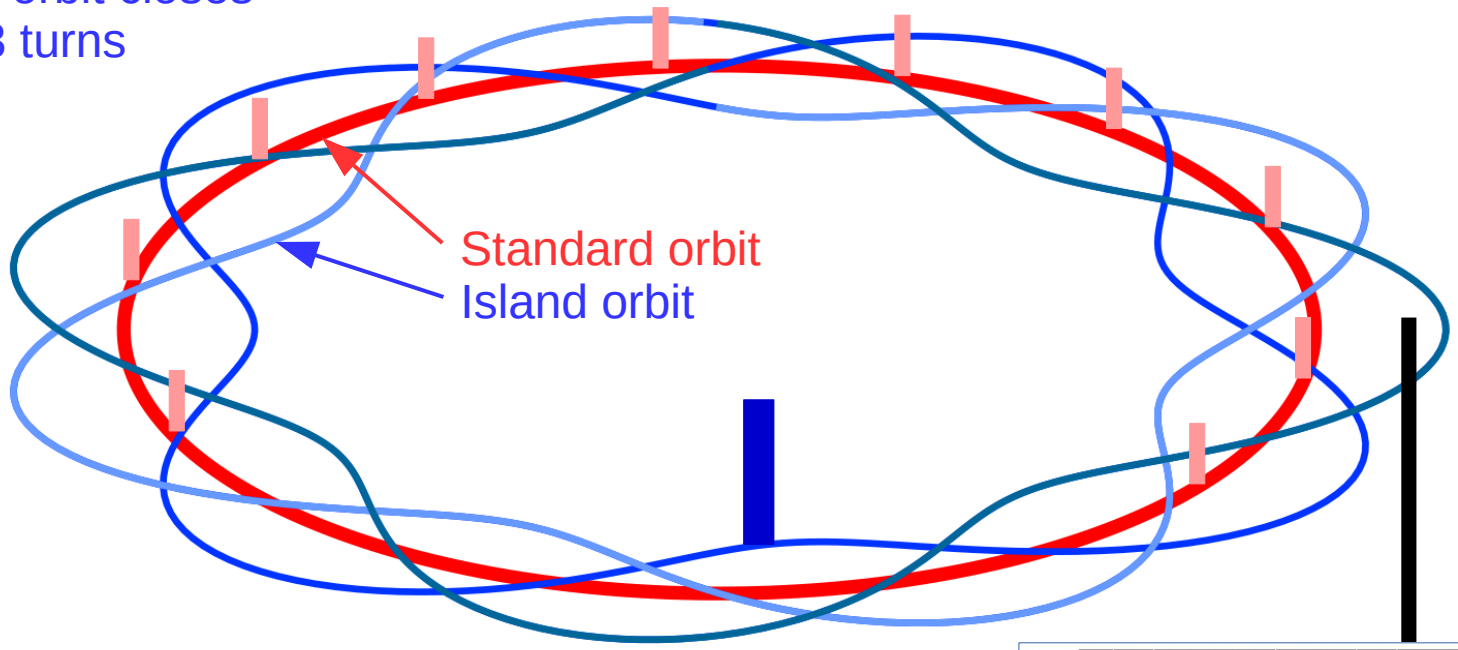
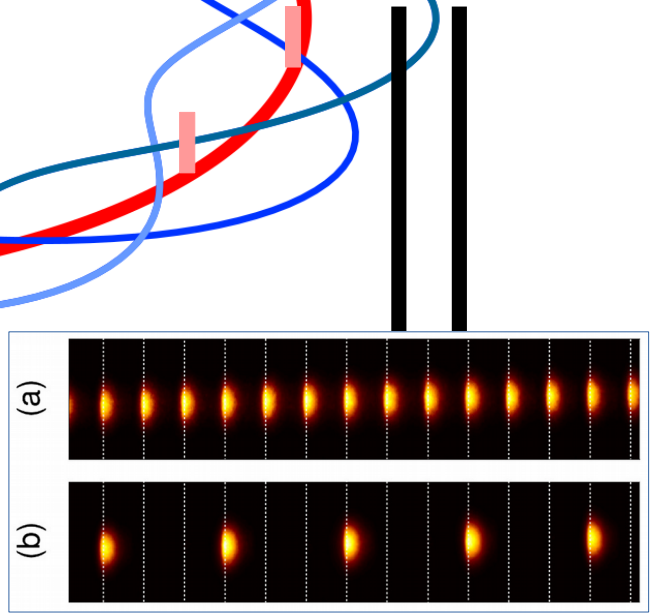
# Application: “Increase Revolution Time”

## 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

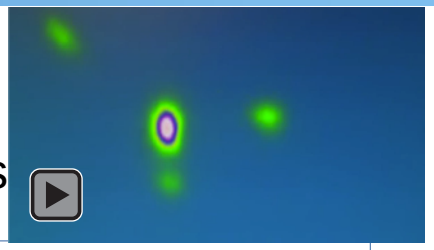
Increasing revolution time, decreasing revolution frequency

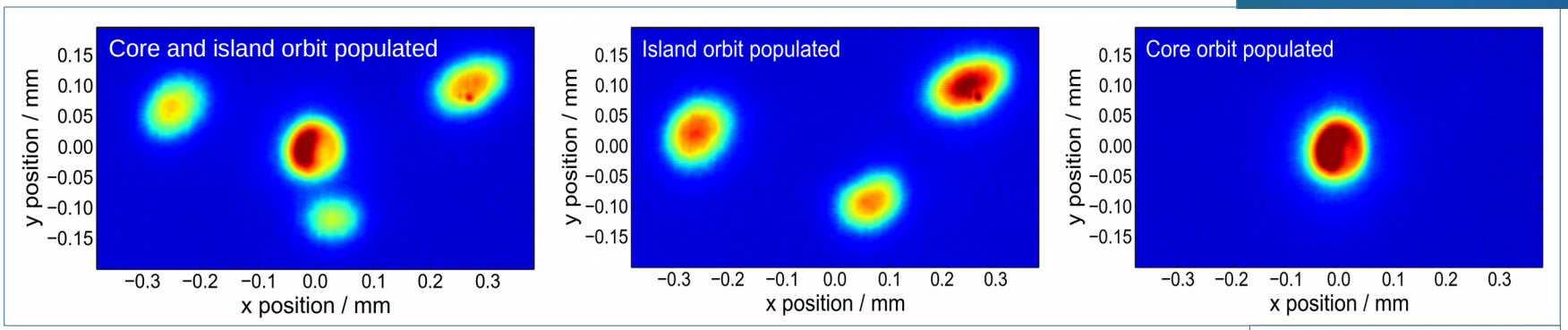
- By the factor = order of resonance
- Decreasing repetition rate at small storage rings for TOF exp.
- **Proof-of-principle User Experiment at the MLS**
  (see T. Arion et. al., Rev. Sci. Instrum. 89, 103114 (2018))

# TRIBs: Fill pattern manipulation

## Fill pattern (or current) manipulation and tunes

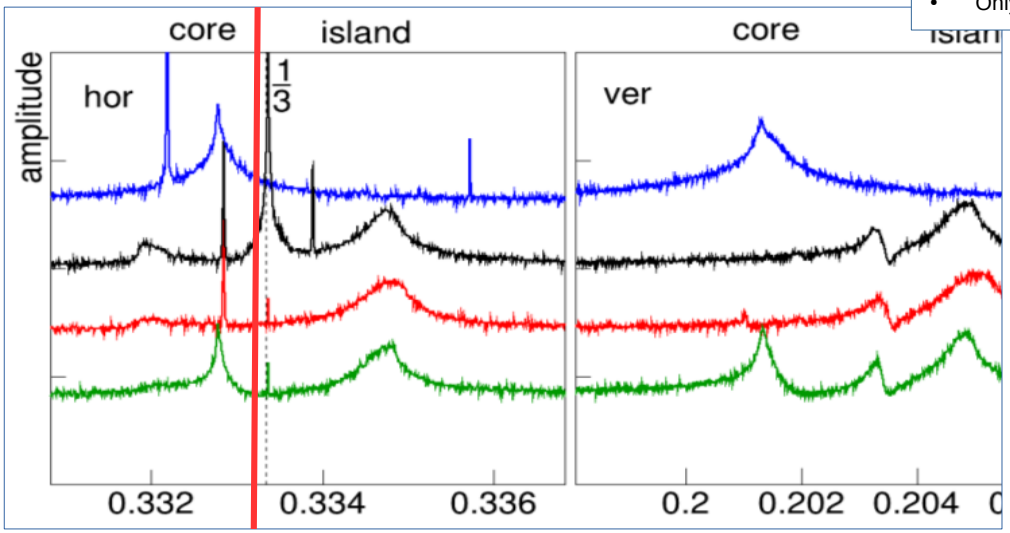
- Electrons can be shuffled between both orbits without losses






(video)

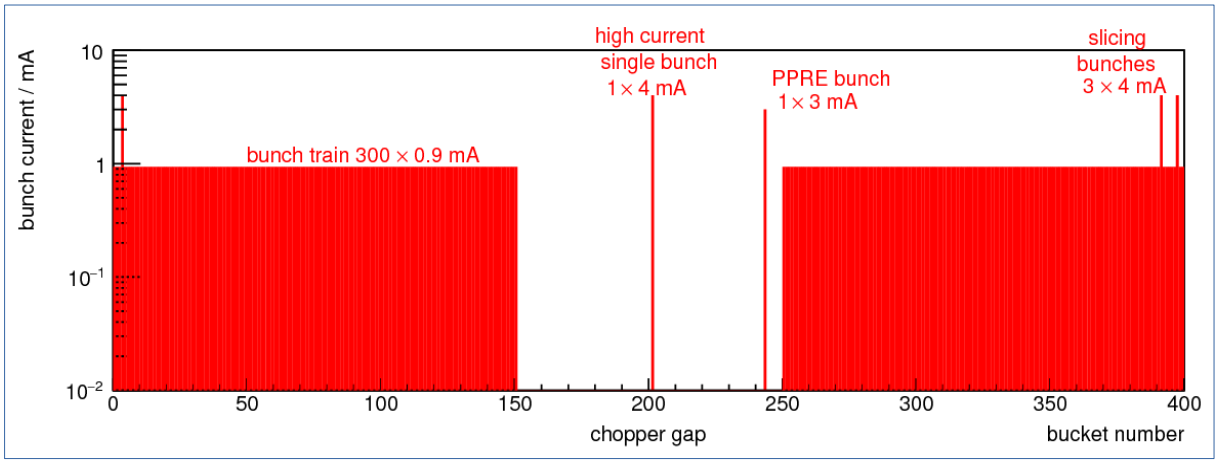
- Core and island orbit populated
- Only core orbit populated
- Only island orbit populated
- Only one island populated




Arbitrary fill pattern within seconds

# Motivation: Provide best Radiation, **simultaneously** !

## Standard Multi Bunch Hybrid Fill Pattern at BESSY II




In addition:
- Single Bunch mode 2-3 weeks per year … 1.25 MHz
- Few Bunch mode 2-3 days per year … 5 – 10 MHz
- Low alpha mode 2 weeks per year

BESSY VSR

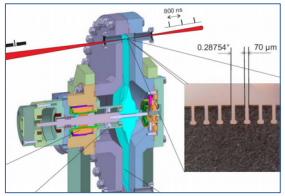
See – https://www.helmholtz-berlin.de/quellen/bessy/betrieb-beschleuniger/betriebsmodi_en.html
or google: BESSY II operation modi

**Bunch Separation Scheme for Gap Less Operation**

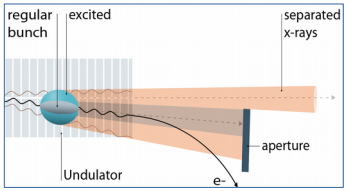
DLSRs, BESSY VSR…

## Pulse or Electron Bunch Separation Schemes

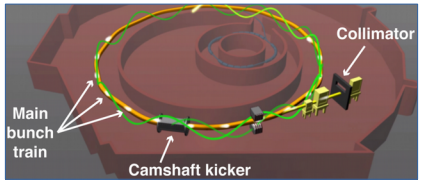
- **Slicing: 100 fs short, but low intensity pulses**
- **X-ray MHZ Chopper**, local at beamlines, photon pulse separation (FZJ, HZB)



- Diffraction Surface Acoustic Waves
- **Pule 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 Deflecting Cavity
- **TRIBs**

# TRIBs at BESSY II: Towards realistic user operation

## 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 beam line, selecting source spot
  - Purity, diffusion rates, SNR
  - Usable at all beam lines 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) ?
  - Injection Scheme

Fall 2016 – 2017

User test week
in February 2018

# TRIBs at BESSY II: Separation at beam lines

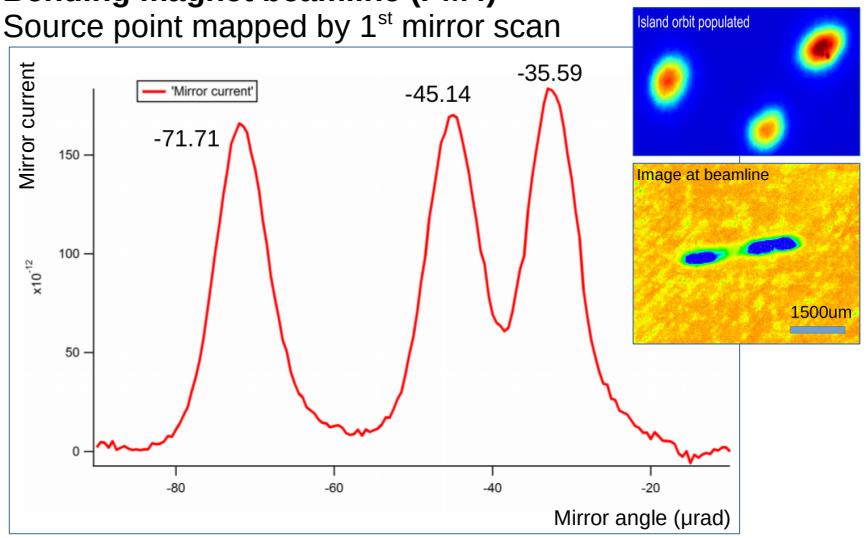
## Common experiments with beam line scientists and in-house users

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

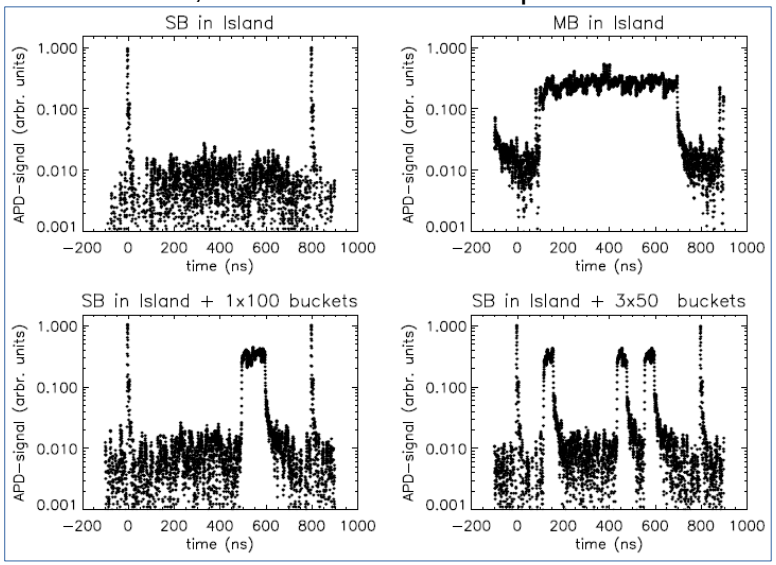
**Successful separation at bending magnet and undulator beam lines**

Achieved purity: > 100, > 1000 depending on beamline

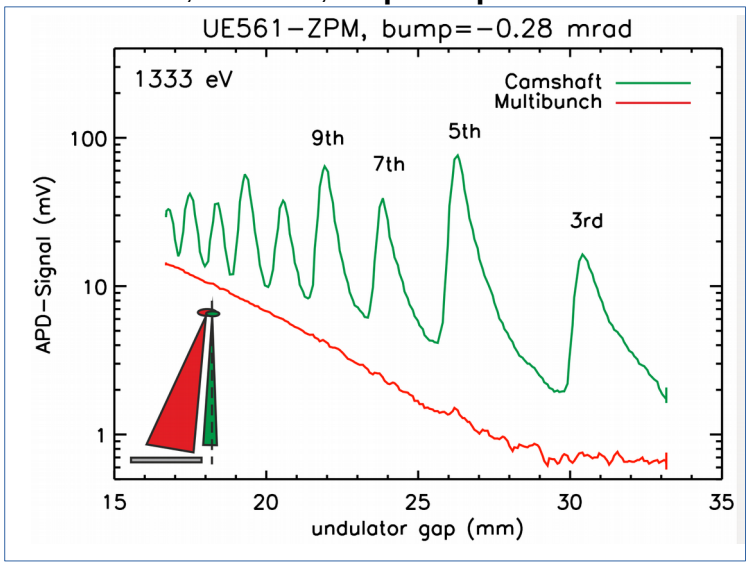
**Bending magnet beamline (PM4)**
Source point mapped by 1st mirror scan




4 ID beam lines (**UE56-1, UE112**, UE49, UE46)
UE56-1 ZPM, 831 eV linear vertical polarized

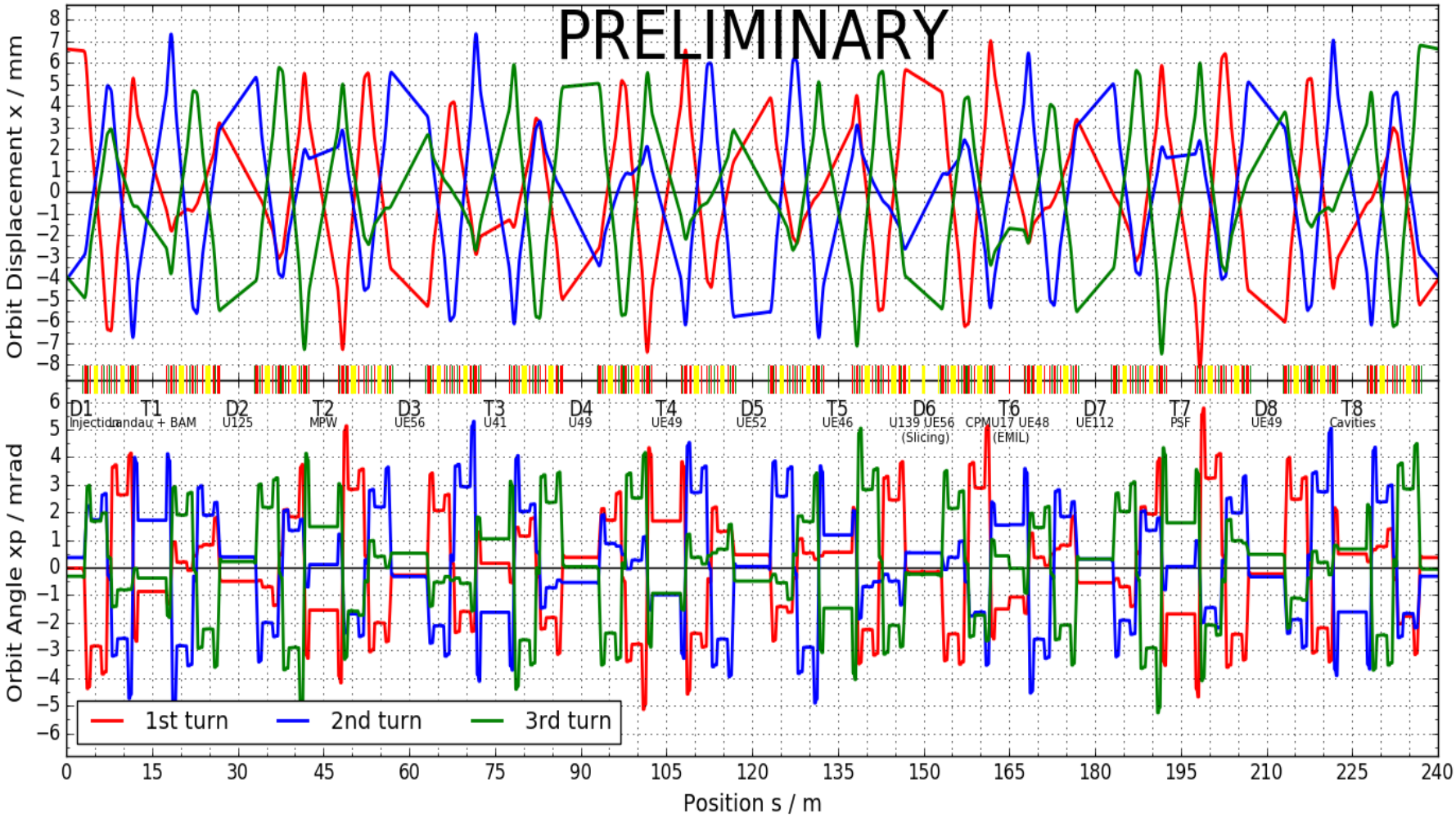



UE56-1 ZPM, 1333 eV, **elliptical polarized mode**



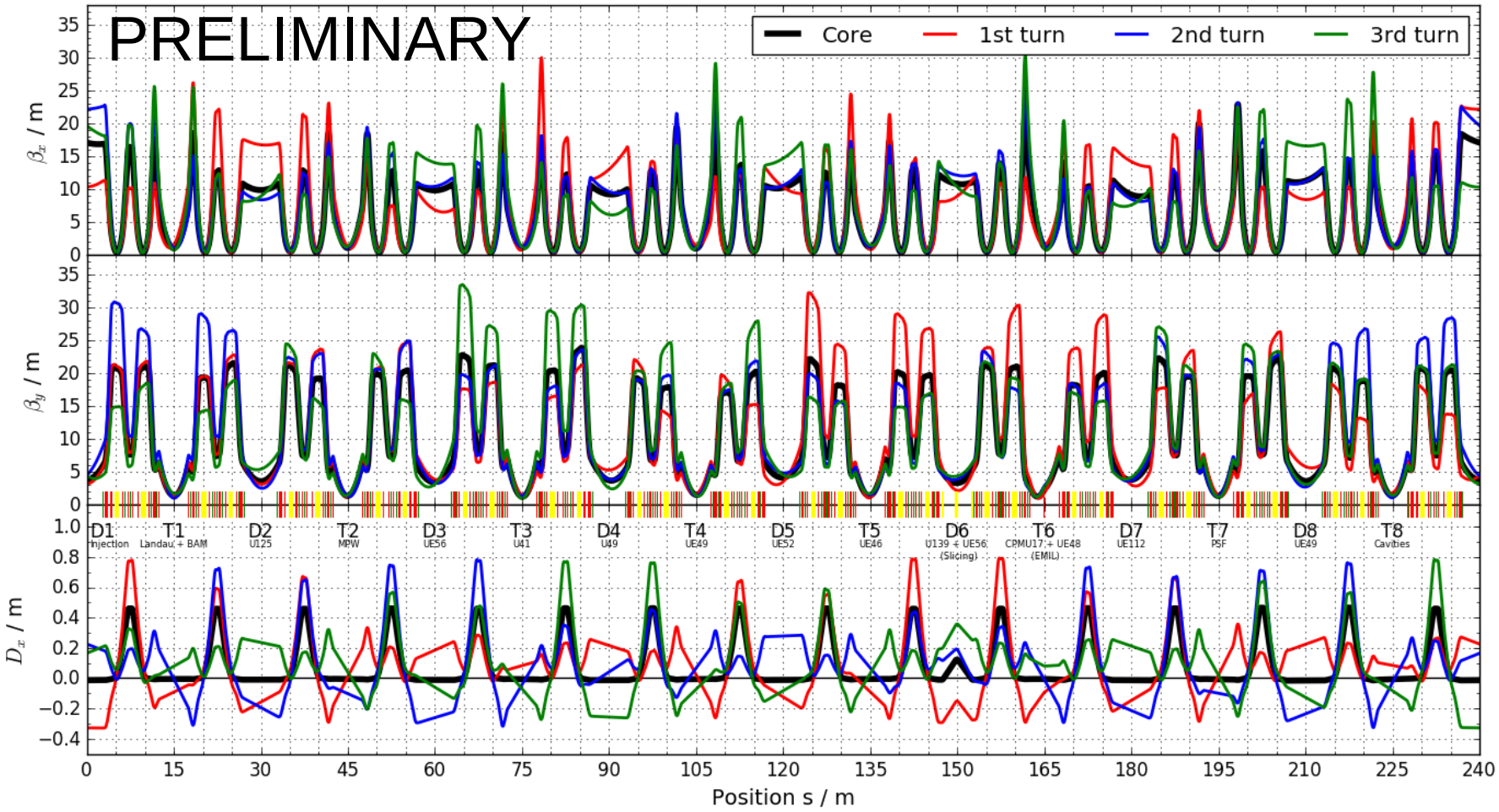
# TRIBs at BESSY II: Separation at beam lines

## Separation – Orbit Displacement and Angle for 2nd Island Orbit




Separation: > 10σ at horizontal source size of $\sigma_x$ ~ 300 mm and divergence of maximal $\sigma_x'$ ~ 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 | |

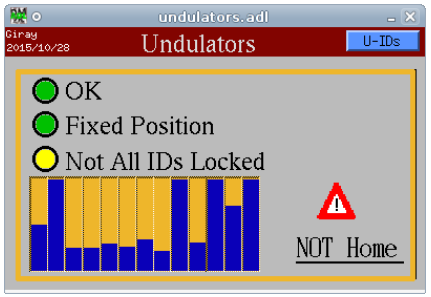
$$\sigma = \sqrt{\beta \cdot \epsilon + (D \cdot \delta)^2)}$$

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

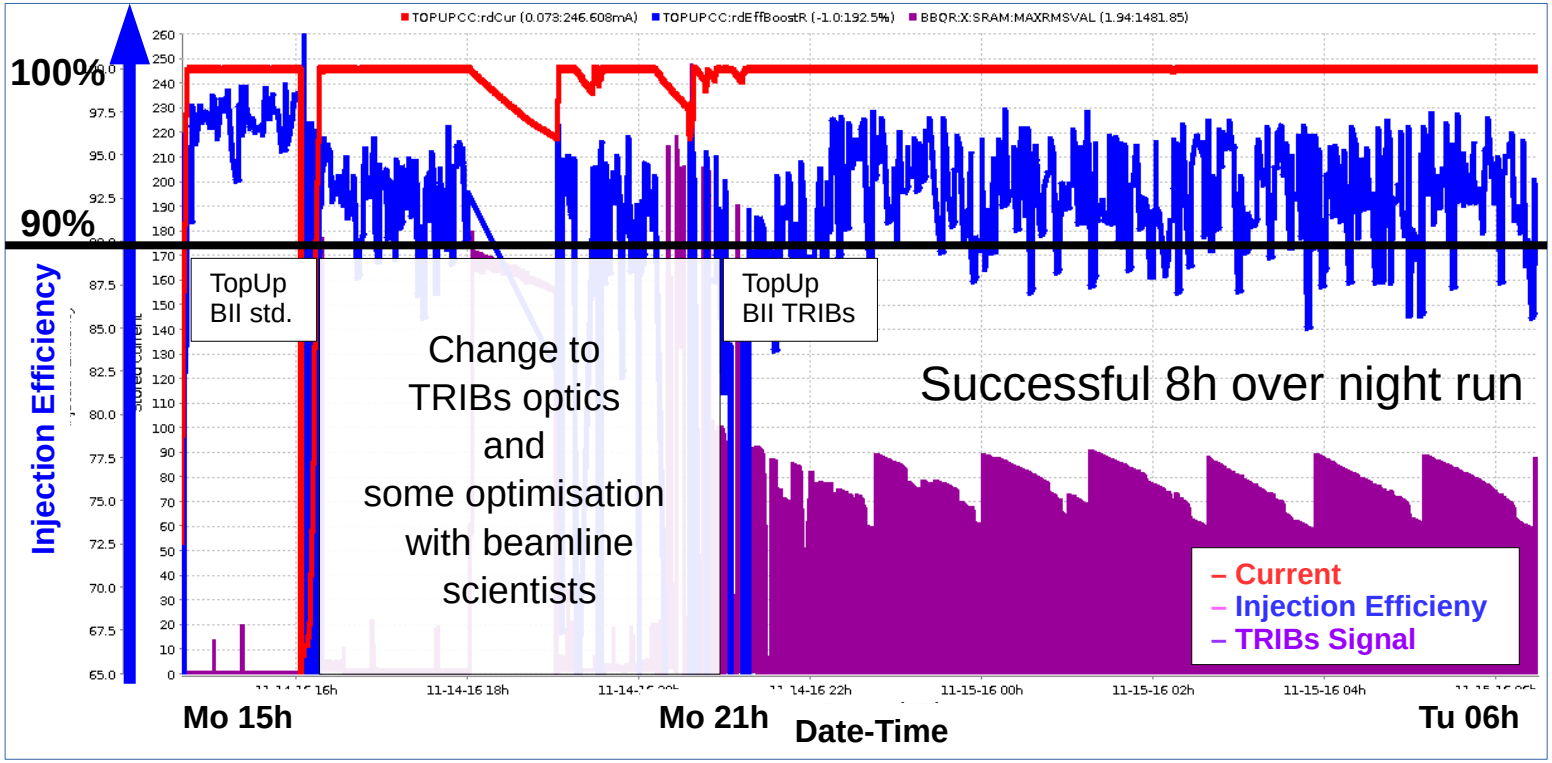
# TRIBs at BESSY II: TopUp Injection

## 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 at BESSY II: Two Orbit User Test Week

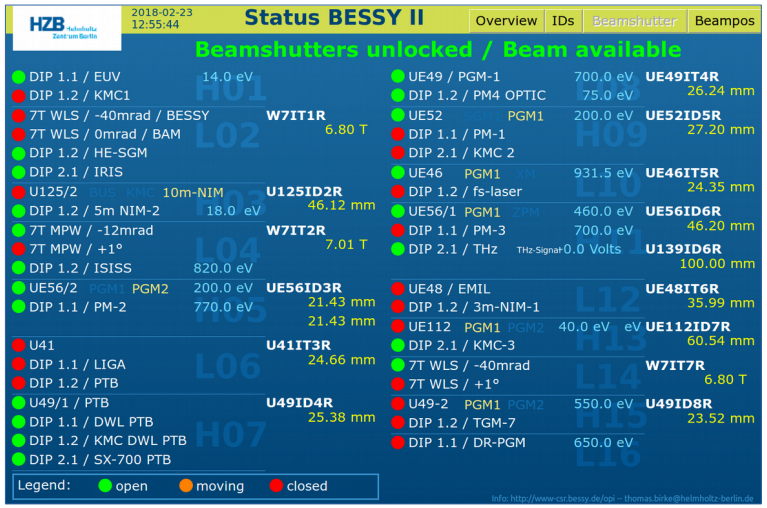
## TRIBs move towards realistic User Operation
## TRIBs/Two Orbit Test Week – February 2018

**19th - 25th February 2018**

- Verify if beam quality 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 (TopUp)
- Verify that multi bunch signal from standard orbit is not disturbed by the island orbit signal
- Increase accessibility of the island orbit at beam lines

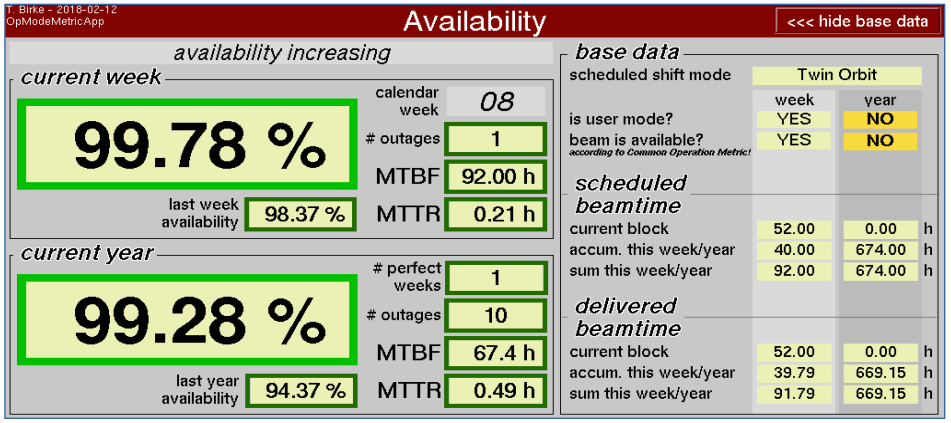
Open beam shutters / beam lines

**20/39,** 23.02.2018, Friday 13:00

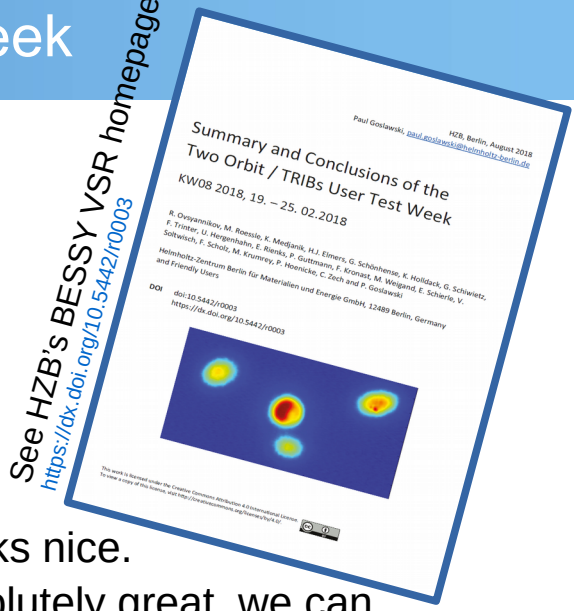



- Demanding daily schedule:
  07-10h: Storage ring optimisation
  **10-16h: Common experiments**
  16-18h: Restoring TRIBs for
  **18-07h: TRIBs User Run**

- 13 User feedbacks
  … Great response!



## TRIBs/Two Orbit Test Week: Summary, Conclusions, Next steps and Outlook




- Two Orbit User Test week report online (see VSR homepage)
  - Feedback helps to develop realistic user operation mode

- **Timing Users: D2, U125** (example)
  "we succeed to adjust our microscope finally. Everything works nice. We have a 1000:1 signal to multibunch ratio in intensity. Absolutely great, we can measure in this mode without problems."

- **Multibunch Users:**
  Taking injection not into account, TRIBs behaves at beamlines with good selection opportunities (flexible apertures, intermediate focus) like the Standard User setting.
  Injection is a problem since the source changes;
  Normalisation of data on beam current difficult

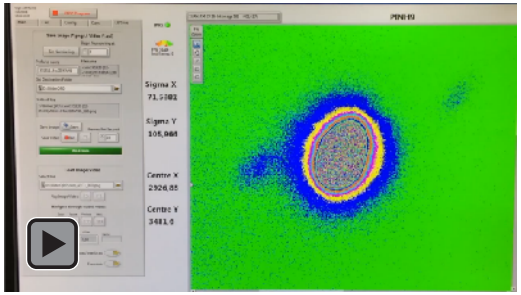
**TRIBs tested successfully in TopUp User Operation**

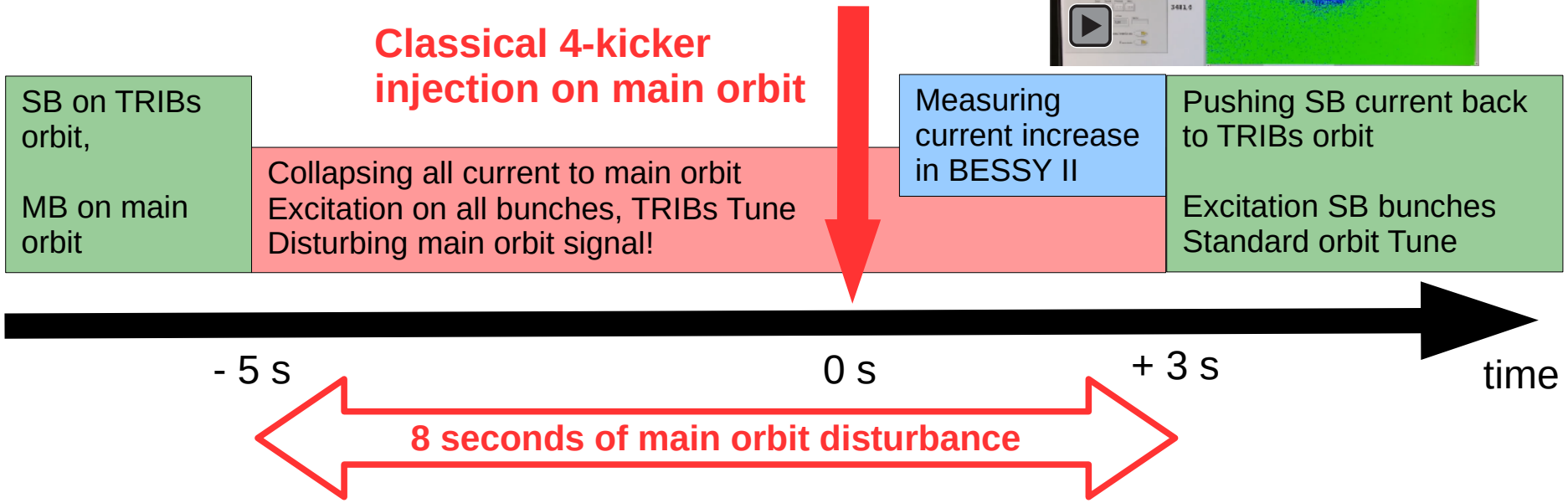
1) Technical topics: Adapt all systems to two orbits!
   (Orbit feedback control, ID compensation, orbit bumps, additional apertures at beamlines, ...

2) Last big conceptual challenge: **TopUp-Injection process**
   - Repopulation of orbits for injection disturbs the signal from standard orbit for too long time → Reduce disturbance or inject directly on island orbit

## Injection into BESSY II's TRIBs optics

- Using classical 4-kicker injection scheme; all current injected on main orbit !
- Therefore all current from island orbit is pushed to main orbit using bunch resolved tune excitation. This bucket cleaning stays on for the whole injection process to force injected charge to move directly on main orbit ➡ this disturbes the main orbit.
- After injection the current increase in BESSY II is measured (this takes up to 2-3 seconds) and then afterwards
- Single Bunch or Few Bunch is pushed back to island orbit





# TRIBs (near) Future

## Pushing towards realsitic user operation & understanding

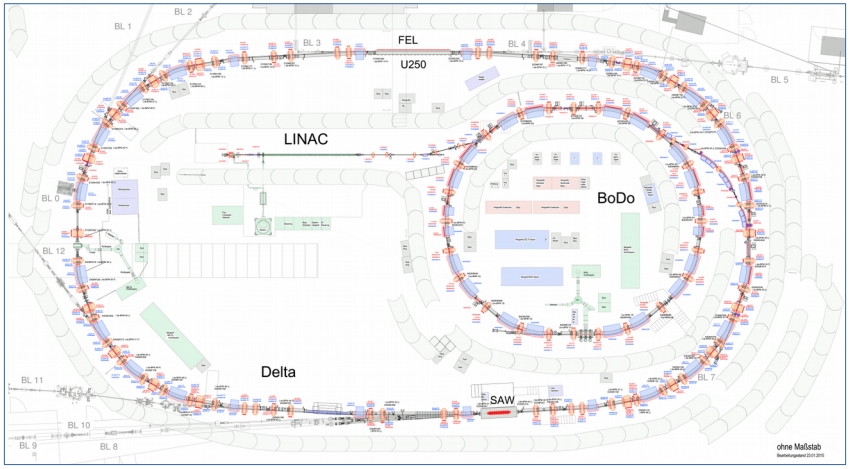
**Next TRIBs User Week**
**Spring 2020**

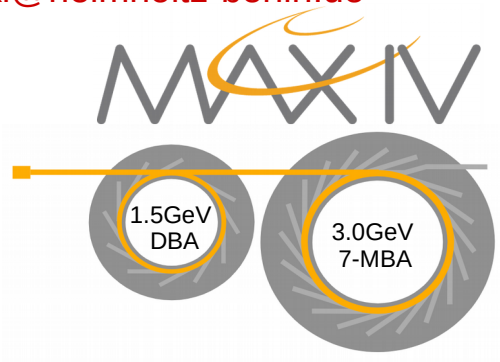
- HZB pushes TRIBs towards a user operation state;
  TopUp Injection at BESSY II and feasibility studies for successor - BESSY III
- Study Group, Collaborators? TRIBs at other facilities – **TU Dortmund/DELTA, MAX IV Laboratory** !
  Many open questions at this non-linear two beam dynamic regime:
  horizontal, vertical islands, trans.-long. coupling, diffusion rates, potential-well depth, lattice design for TRIBs, etc.
- New Verbundforschungsantrag (2019 – 2022) – **TiMo: Ti**ming **Mo**des for Advanced Light Sources
  **PhD positions** – If interested --> paul.goslawski@helmholtz-berlin.de

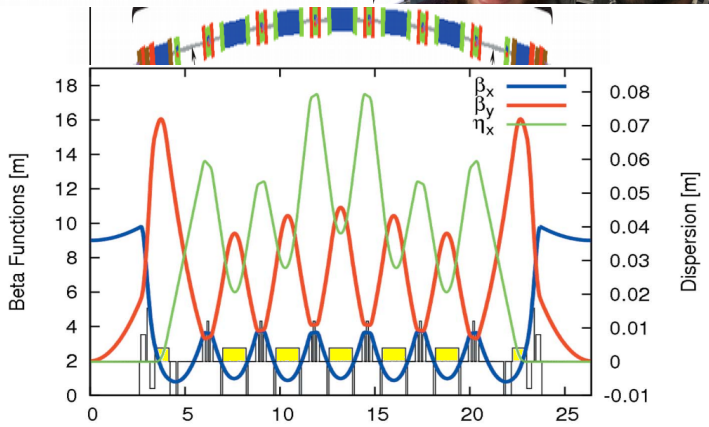
technische universität dortmund

DELTA

1.5 GeV, 115m
CHG, EEHG, Short pulses with Lasers



# Summary: TRIBs at HZB

## Proof-of-Principles Experiments done !

- **Separation scheme**, two stable orbits in one machine,
  2nd fill pattern stored on 2nd orbit tailored for timing experiments
  (average brightness and timing: repetition rate and short bunches)
- Multi-Bunch fill on standard orbit and
  Single Bunch or Few Bunch Filling on island orbit
- Studies towards user operation in a 3rd generation light source,
  → combine with TopUp injection scheme, many IDs (BESSY II / VSR)
  → together with DELTA/TU Dortmund and MAX IV general understanding

**TRIBs for**

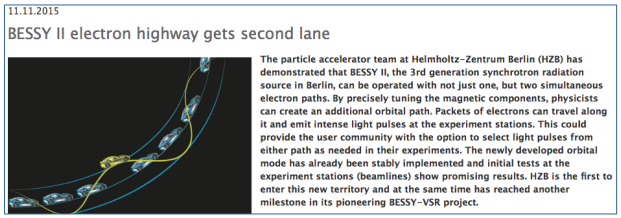
1) BESSY II
2) BESSY VSR
3) BESSY III

4) … others?

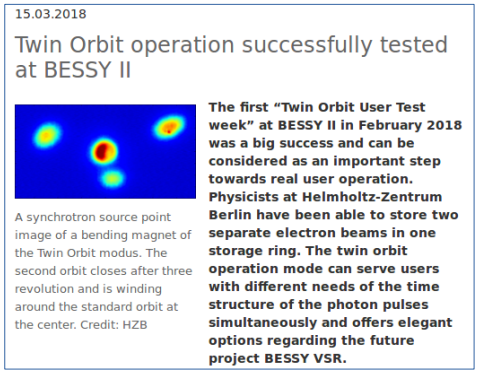
BESSY VSR
Helmholtz-Zentrum Berlin

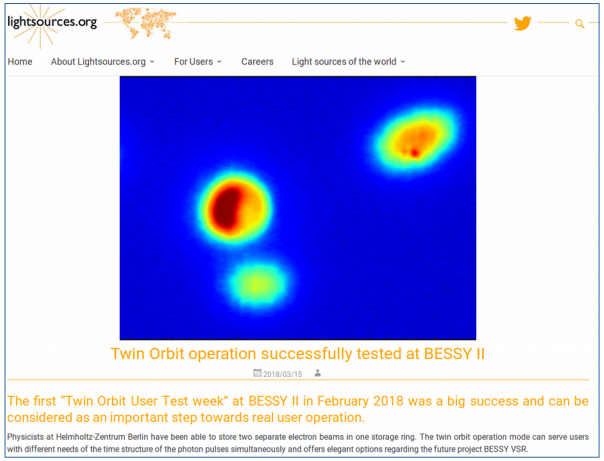
will provide long and short intense bunches
simultaneously → pulse separation mandatory

**Fall 2015** see news
HZB and lightsource.org

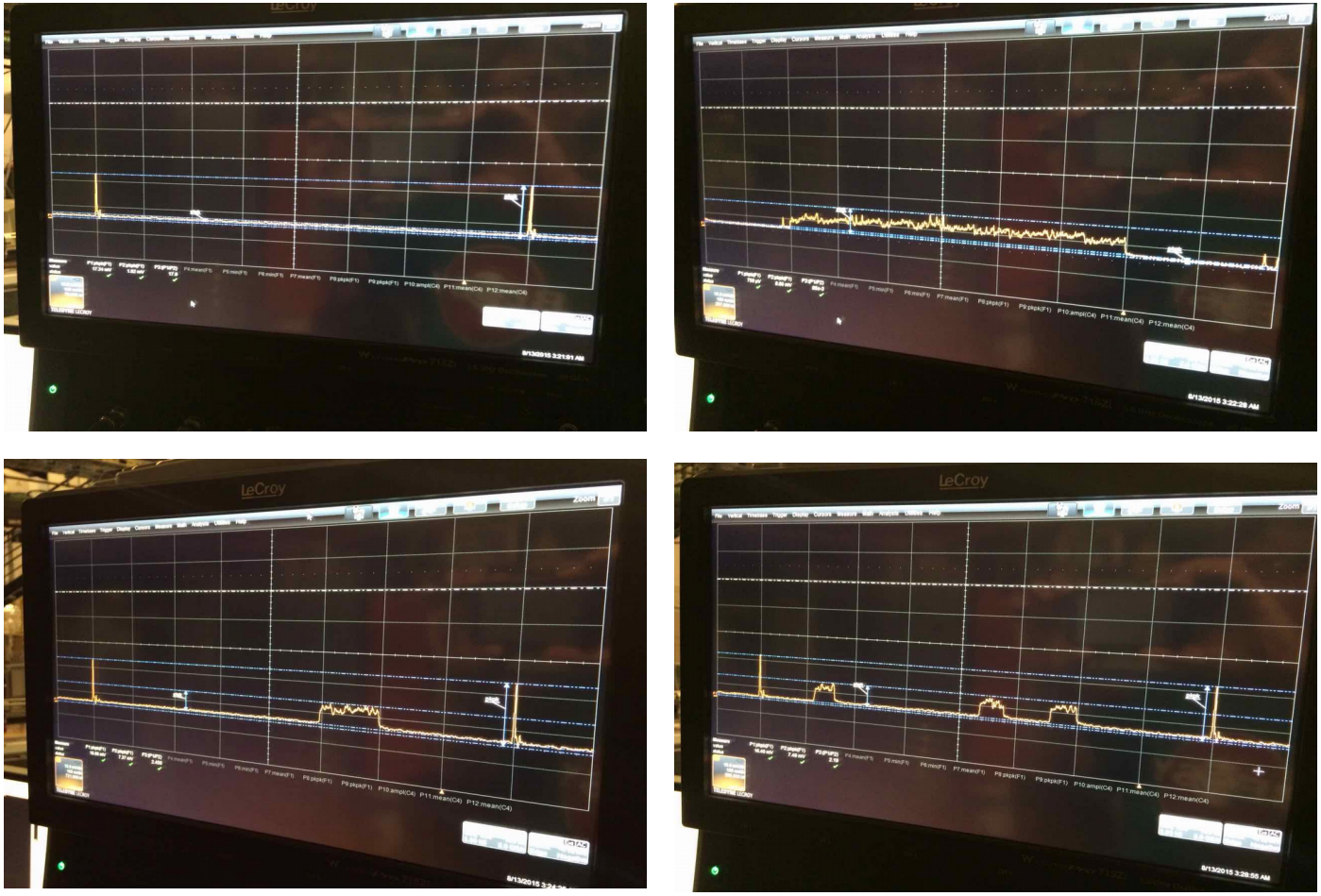




**Spring 2018** see news
HZB and lightsource.org



# Thank you for your attention




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

# References, Team and Acknowledgement

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## Team

*Accelerator group:*
Felix Armborst (Kramer), T. Atkinson, J.Feikes, P. Goslawski,
J.G. Hwang, A. Jankowiak, P. Kuske, J. Li, T. Mertens, M. Ries, A. Schälicke, G. Schiwietz, G. Wüstefeld

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

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